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Waterways Experiment Station

An Evaluation Procedure for Determining the Adequacy of Alluvial River Sediment Data Sets

by William D. Martin

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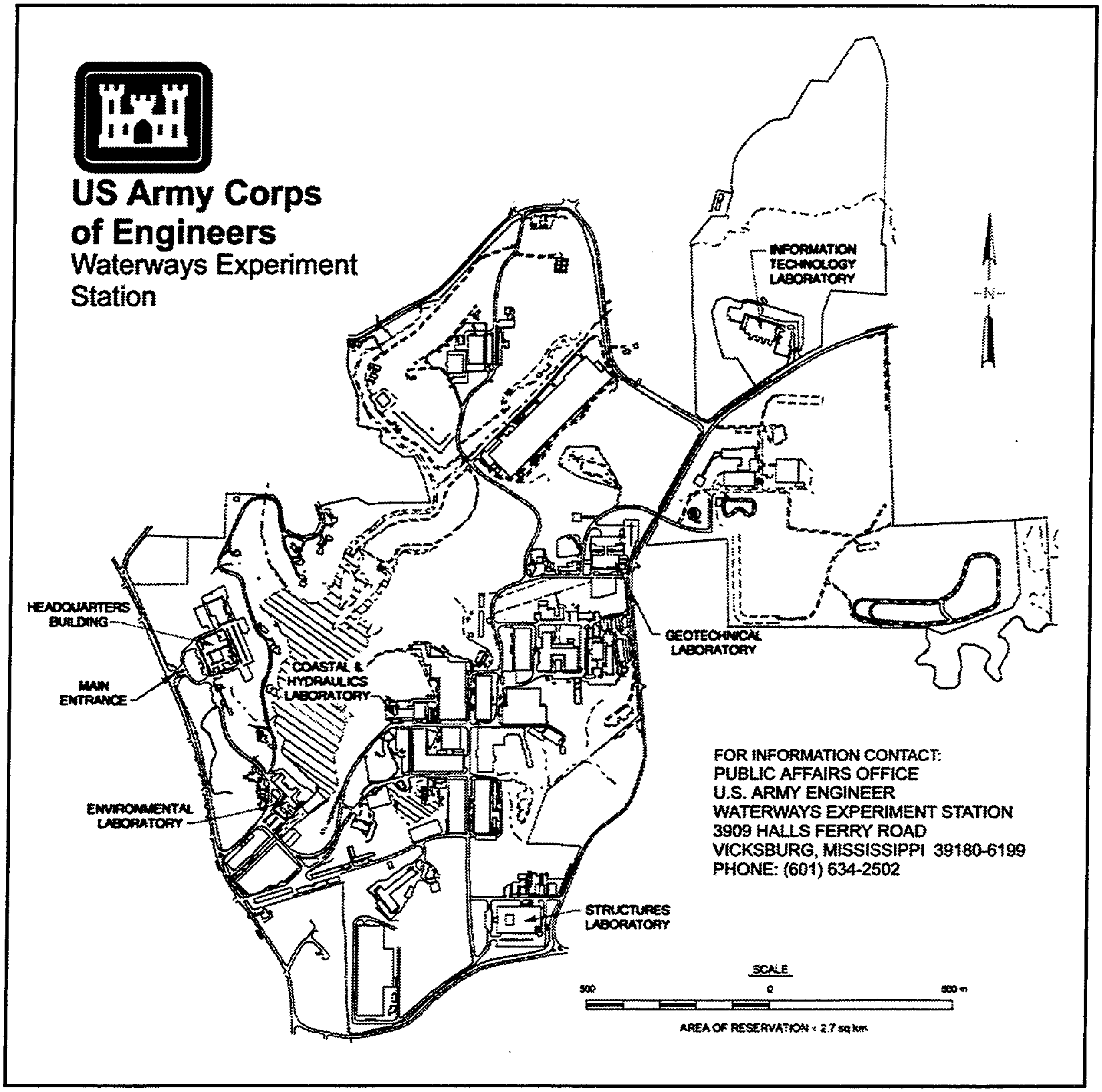

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Preface

The research described in this report was conducted from June 1991 to June 1996 by Dr. William D. Martin, Acting Chief, Hydro-Science Division, Coastal and Hydraulics Laboratory, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS. The work was conducted under the general supervision of Messrs. Richard A. Sager, Acting Director, Hydraulics Laboratory; and Robert F. Athow, Acting Assistant Director, Hydraulics Laboratory.

This report is a dissertation in partial fulfillment of the requirements for the degree of Doctor of Philosophy from the University of Memphis, Memphis, TN.

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1 Introduction

Sediment Sampling

All studies of sedimentation and sediment transport require some degree of field data. These data are necessary whether the study consists of simple observation and correlation of empirical evidence or, at the other end of the spectrum, a complex three dimensional numerical model. It has been suggested (USACE, 1989) that a staged approach to sediment studies is the best approach when the degree of the problem is unknown. This staged approach allows ever more complex steps such that the present step builds on the last. Even such an efficient and prudent method as the step method requires accurate sediment data.

Necessary data to conduct sediment studies vary as to the complexity of the problem and the approach, but for alluvial streams can generally be defined as:

* Channel geometry (cross-section size, cross-section shape, reach length, water surface or energy grade line slope, extent of obstructions and width of flow)
* Stream flow characteristics (i.e., discharge, velocity, depth of flow)
* Water temperature

* Suspended sediment characteristics (grain size and gradation or size fraction distribution)
* Bed sediment characteristics (grain size and gradation or size fraction distribution)

It can quickly be reasoned that the collection and recording of such variables would be both time consuming and expensive. The question now becomes, how much data is necessary? By nature, sediment data is quite variable. Water discharge vs. sediment discharge relationships are typically plotted on log-log paper, with water discharge on the abscissa and sediment discharge on the ordinate axis. For a given water discharge, the associated sediment discharge can vary over several log cycles. Furthermore, other important variables such as grain size distribution in the stream bed and water column can vary by several orders of magnitude. Faced with these degrees of variability, the historic answer to the lead question has been to collect as much data as time and money would allow (USACE 1948) and to hope that the data covered sufficiently variable conditions to provide representative results when placed into the transport functions and used as predictors. This approach is haphazard at best. At worst, it can lead to erroneous conclusions drawn from insufficient or misleading data sets.

Previous Research

Sediment Data Collection and Analysis

Data collection in general tends to be viewed by the hydraulic engineering community as somewhat routine. Perhaps this explains why little is written in the literature on this subject when compared to other subjects which are undoubtedly seen as more research worthy. However, data collection in general is always a significant, if not the major cost for hydraulic and sediment studies. Collection and analysis of sediment data, in particular, tends to be quite expensive. This is due to the variability of the parameters measured (Guy, 1970). The majority of the research in this area was conducted by a fairly limited group of researchers during the 1940's through the 1970's. Research literature after this time is dominated by computer applications and new numerical methods for analyzing and predicting sediment movement.

The problem of data collection for sediment studies, when addressed in the literature, typically focuses on sediment measurement techniques. These sources, of which there are many, relate to equipment (Vanoni, 1975; Shen, 1971; Guy and Norman, 1970; Inter-Agency Committee on Water Resources, Subcommittee On Sedimentation, Reports Number 1 (1940), 2 (1940), 5 (1941), 6 (1952), 11(1957) and 13 (1961)) and measurement and analysis techniques (Vanoni, 1975; Shen, 1971; Shen and Hikkawa, 1980; Inter-Agency Committee on Water Resources, Subcommittee On Sedimentation, Reports Number 3 (1941), 4 (1941), 7 (1943), 8 (1948), 10 (1953), and 12 (1957)).

The time interval for taking sediment samples has been discussed (Guy and Norman, 1970) in terms of adequacy of sediment samples. These discussions indicate that adequate sampling may require that samples be collected on daily, hourly or even bi-hourly sampling. However, Guy and Norman concede that each sample taken costs the same at a station and that monthly sampling over a long period may yield more information and be more cost effective than daily sampling for a short period. The fact that daily samples can often yield little information for the investment has been corroborated (Martin, 1988). It has further been suggested that samples be of sufficient quantity to cover the natural random variation and size gradation of transported sediment (Porterfield, 1972).

The only literature identified which deals with the number of samples necessary to construct an adequate data set of suspended sediment samples is the work of H. P. Guy (1968). The technique was actually intended to determine if sediment samples taken in a vertical were representative. Its purpose was to replace the necessity for computing the algebraic means of different populations in order to quantify a population. Guy developed a statistical technique based on the deviation of measurements from the mean of the suspended sediment concentration. The procedure would assess the quality of a mean for a group of data or the quality of a coefficient based on a ratio of sample means. He presented this technique as a nomograph which would either evaluate an existing data set or predict the number of samples required based on an assumed sum of squared deviations from the mean and a desired level of confidence.

In summary, previous research as to how many sediment samples are necessary to achieve the best results has been very limited. What research that has been done has almost exclusively focussed on equipment, measurement and analysis techniques. Guy (1968) developed some guidance for the number of samples require to provide a desired level of confidence in the population mean of samples in a vertical section of a steam cross section. Since Guy's work, there has been no additional research as to how many sediment samples are necessary to describe the sediment characteristics at a sediment sampling station. It is currently assumed that sediment samples will be collected for a given duration, with this duration controlled primarily by the funds available for the study.

Sediment Transport Functions

Sediment transport functions, per se, (the term 'functions' is used throughout because as a group these exist in the form of graphical solutions, complex formulations and regression derived equations) are not the topic of the research presented herein. However, since they are used as part of a procedure for determining the adequacy of sediment data at a sampling station, it seemed prudent to provide some background as to their theoretical development. Sediment transport in streams occurs in three ways. It is either moved along and in contact with the bed, by saltation (skipping and bouncing along the bed) or in suspension. One or more of these may occur simultaneously. The transport processes of rolling and saltation occur very near the bed. Sediment transported in these manners is denoted bed load (Vanoni, 1975). The zone of bed load transport is variously reported as two bed particle diameters thick (Julien, 1995) or a few bed particle diameters (USACE, 1989). The suspended load is sediment transport that occurs in the zone above the zone of bedload transport and extends to the water surface. Total load is the combination of bed load and suspended load. To complete this definition of terms, the suspended load is further divided into bed material load and wash load. Bed material load is comprised of sediment particles found in appreciable quantities in the bed. Wash load is comprised of very small particles found in very small quantities in shifting portions of the bed (Vanoni, 1975).

Sediment sampling, as conducted by the United States Geological Survey in the St. Francis River basin, collects samples of suspended sediment from the entire water column with the exception of the portion within 0.3 to 0.4 feet of the bottom (Guy and Norman, 1970). This unsampled zone contains all of the bed load in sand bed streams and a small potion of the suspended load.

The pioneering work in sediment transport computation was done by M. P. Duboy (1879). His work was based on the concept that sediment moves in thin layers along the stream bed. The basis of his approach was that the applied bed shear stress, τ_0, must exceed the critical shear stress, τ_c, in order to initiate motion. Duboy's equation is presented below, in English units.

$$q_{bv} = \frac{0.173}{d_s^{\frac{3}{4}}} \tau_0 [\tau_0 - 0.0125 - 0.019 d_s] \qquad (1)$$

where

q_{bv} = volume of bed material in motion, per foot of width

d_S = particle size in millimeters

τ_0 = boundary shear stress in lb/ft

Julien (1995) has classified sediment transport functions into three categories based on the basic approach involved in their derivation. These are (1) formulations based on advection-diffusion, (2) formulations based on energy concepts, and (3) empirical methods based on regression analysis and graphical procedures. While many sediment transport functions have been proposed since the pioneering work of Duboys, no one function accurately and consistently works for all applications. In practice, one typically selects several functions based on their applicability to a given stream. This applicability is based on the similarity of data from which the function is developed to that found on the stream in question. The function results are then compared in some manner to field data and the one that best fits the field data is selected (Julien, 1995).

Three approaches are discussed below. These represent one from each type of formulation, as presented above. Each of these was used in this dissertation.

Colby's Method. Colby (1964) used the very complex Einstein bed material function (Einstein, 1950) which built on Einstein's earlier bedload transport function (Einstein, 1942). Einstein's function was based on the statistical probability of a particle initiating motion. He combined this with advection-diffusion principles to develop his bed material function. Colby developed his relationship based on an immense amount of stream and flume data. He used measurements from a score of streams including the Niobrara River, the Middle Loup River, the Colorado River and the Mississippi River. In addition, he augmented these data with flume data collected in three different size flumes. Colby applied the Einstein bed material function to the computation of bed material discharge for a given size of bed sediment over a wide range of velocities, depths and water temperatures to fill gaps in the stream and flume data. He also added a correction for sediment concentrations in excess of 10,000 parts per million and for temperatures more or less than 60 degrees Fahrenheit. Colby presented his results as a series of four graphs. In order to apply the Colby method, one need only know water depth, mean velocity, temperature and sediment concentration. Colby's method is theoretically applicable over a range of water depths from .1 feet to 100 feet deep, velocities from 1.0 to 10.0 feet per second, median bed sand sizes from 0.10 to 1.0 millimeters in diameter, water temperatures from 32-100 degrees Fahrenheit and sediment concentrations up to 200,000 parts per million. Its wide range of applicability, ease of use and relative accuracy have all contributed to the popularity of this method. It was particularly popular prior to the advent of computer based sediment transport calculations. In recent years, it has lost some prestige to other methods that provide better results and whose complexity are not an obstacle to computer generated results (Yang, 1991).

Yang's Method. Yang (1973) seized upon the findings of Cook (1945) and Bagnold (1960) to develop his method which is founded on the notion of stream power. Stream power, as was proposed by Cook and Bagnold, is the rate at which a stream loses energy per unit area of the boundary. For three-dimensional flow and a boundary that includes the banks, the stream power is given as

$$\gamma RSV$$

or the product of the total shear and the mean velocity. Yang modified this definition and expressed stream power as rate of potential energy dissipated per unit weight of water. This is defined as VS or the product of the mean velocity and the energy slope. Yang's dimensionless unit stream power equation is:

$$\begin{aligned} \log C_{ppm} &= 5.435 - 0.286\log\omega\frac{d_s}{\nu} - 0.457\log\frac{u_*}{\omega} \\ &+ [1.799 - 0.409\log\omega\frac{d_s}{\nu} - 0.314\log\frac{u_*}{\omega}] \\ &\cdot \log[\frac{VS}{\omega} - \frac{V_c S}{\omega}] \end{aligned} \qquad (2)$$

where

C_{ppm} = the concentration of bed-material discharge in parts per million by weight.

ω = the average fall velocity, in feet per second of sediment particles of diameter d_{50}

d_S = the particle size in feet at which 50 percent of the bed material by weight is finer

υ = the inematic viscosity in feet squared per second

u^* = the shear velocity in feet per second

V = the average velocity in feet per second

S = the energy slope in feet per foot

V_C = the average flow velocity in feet per second at incipient motion

The sediment transport, in tons per day, is related to Yang's concentration value by

$$Q_S = Q_W \, C \, k \tag{3}$$

where

Q_S = sediment transport in tons per day

Q_W = water discharge in cubic feet per second (English units) or cubic meters per second (metric)

C = sediment concentration in parts per million

k = 0.0027 (English) or 0.0864 (metric)

The coefficients for Yang's equation were developed from 463 sets of laboratory data. Yang's equation was developed from data ranging from 0.137 to 1.71 millimeters median sieve diameter and for water depths of 0.037 to 49.9 feet. Yang's equation has proven to be remarkably reliable over a wide range of sand bed streams in actual use. In a comparison with seven other widely accepted transport equations, based on 1,119 sets of laboratory data and 319 sets of stream data, Yang's equation proved most accurate (Yang and Wan, 1991). However, no one equation has yet been developed that is universally more accurate than all others (Julien, 1995).

Brownlie's Method. Brownlie (1981) chose yet a different approach from the two previously discussed. He reasoned that sediment data from streams was too variable to lend itself to physics-based analysis. He therefore developed his method based on dimensional analysis and regression techniques. Brownlie proposed that a relationship for sediment concentration should have the general form

$$C = f[q, S, g, \rho, \nu, \rho_s, d_{50}, \sigma_g] \tag{4}$$

where

C = sediment concentration

q = water discharge, per unit width

S = water surface slope

ρ = density of water

υ = kinematic viscosity

ρ_s = specific gravity of the sediment particle

d_{50} = median grain size

σ_g = gradation coefficient

Brownlie rearranged the eight independent variables into five dimensionless groups, shown below.

$$C = f[q_*, S, \sigma_g, R, \frac{\rho_s - \rho}{\rho}] \tag{5}$$

where

q_* = dimensionless water discharge

R = Reynold's number

and the other variables are as described above.

By calculation and further combining of the terms, Brownlie arrived at the final form of his equation.

$$C = f[F_g, \frac{r}{D_{50}}, S, \sigma_g, R_g, \frac{\rho_s - \rho}{\rho}] \tag{6}$$

where

F_g = grain Froude number

r = hydraulic radius

R_g = grain Reynolds number

and the other variables are as described above.

Using a data base of unprecedented size (5,263 laboratory sets and 1,764 stream sets), Brownlie used multiple regression analysis to develop his relationship. The final form is

$$C = 7115 c_F (F_g - F_{go})^{1.978} S^{0.6601} \left(\frac{r}{d_{50}}\right)^{-0.3301} \tag{6}$$

where

c_F = coefficient which equals 1.0 for laboratory data and 1.268 for stream data

F_{go} = critical grain Froude number

and the other variables are as described above.

Brownlie's method is applicable to rivers with sand size bed material ranging from 0.02-76.113 millimeters median diameter, average velocities between 0.472 - 5.188 feet per second, depths of .06 - 53.9 feet deep, slopes of .0000021 - .0126 feet per foot and water temperatures of 32 - 96.8 degrees Fahrenheit.

Entropy and Water Resources.

The notion of using entropy as a measure of the degree of ignorance as to the true state of a thermodynamic system dates to the 19th century (Boltzman, 1872). It was then that Boltzman described entropy as:

$$H = k \log p \tag{7}$$

where H is the entropy, p is the probability of system state, and k is Boltzman's constant. C. E. Shannon incorporated entropy into his Mathematical Theory of Communications (Shannon, 1948a, 1948b). This work was developed in five parts and included 23 Theorems associated with the transmission, receipt and recovery of messages sent electronically. In the first of these parts, "Discrete Noiseless Systems" Shannon discussed communication theory as relates to discrete systems such as telegraphs. He introduced entropy as a measure of uncertainty involved between a signal sent and the one received. He stated that the ratio of the entropy of a source to the maximum entropy it could have should be denoted its relative entropy. This value was identified as the maximum compression possible when signals are encoded for a given language's alphabet. One minus the relative entropy was defined as the redundancy. The redundancy of ordinary English was stated to be 50%. This meant that written English is one half determined by the structure of the language and one half is freely chosen by the author. Part II addressed a discrete channel with noise introduced which corrupted the sent signal. Shannon developed mathematical theories to determine errors on the receiving end and correct these errors based on a corrective channel capacity greater than the average error, determined partially through entropy calculations. Part III outlined the mathematical preliminaries of the next parts. In this part, the notion of discrete probability distributions was introduced. Discrete distributions represent continuous functions as groups of occurrences, such as those associated with the dots and dashes of telegraphy. Continuous distributions, such as those associated with the spoken word, were also presented. Of note was the finding that, in the discrete case, entropy measures in an absolute way randomness of the chance variable. In the continuous case, the entropy is a measure of randomness relative to an assumed standard, namely the coordinate system. However, in either case entropy is an important measure of uncertainty due to the fact that the derived concepts of information rate and channel capacity depend on the difference of two entropies and this difference does not depend on the coordinate system as each of these two term's coordinate systems are changed by the same amount. The final parts addressed the capacity of a continuous channel and fidelity evaluation factors.

More current research using entropy concepts developed by Shannon has been presented by E. T. Jaynes, (1957a, 1957b) in the field of informational theory and statistical mechanics for the prediction of equilibrium thermodynamic properties. In these articles, Jaynes introduced informational theory which provides a constructive criterion for setting up probability distributions on the basis of partial knowledge. This is developed to a type of statistical inference which is called the maximum entropy estimate which is formally known as the Principle of Maximum Entropy. This estimate provides the least biased estimate possible based on the information given. Statistical mechanics were presented as a form of statistical inference rather than a physical theory. Jaynes considered the terms "entropy" and "uncertainty" as synonymous. He sketched Shannon's proof that the quantity which is positive, increases with increasing uncertainty and is additive for independent sources of uncertainty is given by:

$$H(p_1 \ldots p_n) = -K\sum_{i=1}^{n} p_i ln p_i \tag{8}$$

where

H is entropy

K is a positive constant

p_i is the probability distribution

The above equation is the Shannon Entropy Function. Jaynes sketched the proof of this function as follows. "The variable x can assume the discrete values $(x_i, \ldots x_n)$. Our partial understanding of the processes which determine the value of x can be represented by assigning corresponding probabilities $(p_i, \ldots, p_n)$. We ask, with Shannon, (1948a) whether it is possible to find any quantity $H(p_1 \ldots p_n)$ which measures in a unique way the amount of uncertainty represented by this probability distribution. It might at first seem very difficult to specify conditions for such a measure which would ensure both uniqueness and consistency, to say nothing of usefulness. Accordingly, it is a very remarkable fact that the most elementary conditions of consistency, amounting to really to only one compositional law, already determines the function $H(p_1 \ldots p_n)$ to within a constant factor. The three conditions are:

(1) H is a continuous function of the p_i.

(2) If all p_i are equal, the quantity $A(n) = H(1/n, \ldots, 1/n)$ is a monotonic increasing function of n.

(3) The composition law. Instead of giving the probabilities of events $(x_1 \ldots x_n)$

directly, we might group the first k of them together as a single event, and give its probability $w_1 = (p_1 + ... p_k)$; then the next m possibilities are assigned the total probability $w_2 = (p_{k+1} + ... + p_{k+m})$, etc. When this much has been specified, the amount of uncertainty as to the composite events is $H(w_1 ... w_r)$. Then we give the conditional probabilities $(p_1/w_1,...,p_k/w_1)$ of the ultimate events $(x_1 ... x_k)$, given that the first composite event had occurred, the conditional probabilities for the second composite event, and so on. We arrive ultimately at the same state of knowledge as if the $(p_1 ... p_n)$ had been given directly, therefore if our information measure is to be consistent, we must obtain the same ultimate uncertainty no matter how the choices were broken down in this way. Thus, we must have

$$H(p_1 ... p_n) = H(w_1 ... w_2) + w_1 H(p_1/w_1,...,p_k/w_1)$$
$$+ w_2 H(p_{k+1}/w_2,...,p_{k+m}/w_2) + ... \quad (9)$$

The weighting factor w_1 appears in the second term because the additional uncertainty $H(p_1/w_1,...,p_k/w_1)$ is encountered only with probability w_1. For example, $H(½, 1/3, 1/6) = H(½, ½) + 1/2H(2/3, 1/3)$.

From condition (1), it is sufficient to determine H for all rational values

$$p_i = n_i / \sum n_i, \quad (10)$$

with n_i integers. But then condition (3) implies that H is determined already from the symmetrical quantities $A(n)$. For we can regard a choice of one of the alternatives $(x_1...x_n)$ as a first step in the choice of one of

$$\sum_{i=1}^{n} n_i$$

equally likely alternatives, the second step of which is also a choice between n_i equally likely alternatives. As an example, with $n = 3$, we might choose $(n_1,n_2,n_3) = (3,4,2)$. For this case the composition law becomes

$$H(\frac{3}{9},\frac{4}{9},\frac{2}{9})+\frac{3}{9}A(3)+\frac{4}{9}A(4)+\frac{2}{9}A(2)=A(9) \tag{11}$$

In general, it could be written

$$H(p_1...p_n)+\sum_i p_i A(n_i)=A(\sum_i n_i) \tag{12}$$

In particular, we could choose all n_i equal to m, where-upon (12) reduces to

$$A(m)+A(n)=A(mn) \tag{13}$$

Evidently this is solved by setting

$$A(n)=K\ \ln n \tag{14}$$

where, by condition (2), K>0. For a proof that (14) is the only solution of (13), we refer the reader to Shannon's paper (1948a). Substituting (14) into (12), we have the desired result."

$$H(p_1 \ldots p_n) = K \ \ln(\sum n_i) - K\sum p_i \ln n_i$$
$$= -K\sum_i p_i \ln p_i \tag{15}$$

The application of entropy principles to water resources has been applied by Sonuga (1972, 1976) concerning the rainfall-runoff relationship and hydrologic frequency analysis. Amorocho and Espildora (1973) used the Principle of Maximum Entropy to analyze the uncertainty in stream flow computed using the Stanford Watershed Model. V. P. Singh has been one of the most prolific researchers to apply entropy principles to water resources in recent years. His works have addressed the derivation of frequency distributions commonly used for hydrologic analyses using Jayne's Principle of Maximum Entropy, (Singh, Rajagopal, and Singh, 1986). A stochastic model for total sediment yield predictions based on direct runoff volume using entropy principles was developed and compared favorably for several watersheds, (Singh and Krstanovic, 1987). V. P. Singh and M. Fiorentino (1992) published an exhaustive historical perspective of entropy applications in water resources. The period covered included 1962-1991. Subjects covered included fluvial geomorphology (Leopold and Langbein, 1962); open channel hydraulics (Chiu, 1986, 1988; Barbe et al., 1991); redundancy measures for water distribution networks (Awumah et al., 1991); assessment of numerical model performance (Amorocho and Espildora, 1973; Chapman, 1986); data acquisition related to sampling intervals for ammonia concentrations in France and stream flow measurements in Turkey (Harmancioglu, 1981, 1984); rainfall network design (Krstanovic and Singh, 1988a, 1988b); catchment modeling (Jowitt, 1991); and a large body of work addressing the use of entropy-based probability distribution function parameter estimation and comparisons of this method with other parameter estimating methods (Jowitt, 1979; Singh and Jain, 1985; Jain and Singh, 1986; Arora and Singh, 1987a, 1987b, 1989; Singh, Singh, 1985a, 1985b, 1985c, 1988; Arora and Singh, 1989; Fiorentino et al., 1987a, 1987b; Singh et al., 1989, 1990a, 1990b; and Singh and Rajagopal, 1987).

Knowledge Gap

There exists a paradox in sedimentation engineering of the latter 20th Century. Resources to collect data and conduct sediment studies are limited. However, the repercussions of improper or ill advised engineering have never been greater, due to increased land costs, dense population and the litigious nature of society.

The advent of high speed computing and software to take advantage of this capability, have led to unprecedented ability to analyze and predict sediment behavior under a wide variety of conditions. The area where knowledge is lacking is in the data collection arena. As stated previously, these data are expensive to collect and analyze. Field data are necessary to calibrate and verify complex numerical models. Data collected in good faith can still lead to erroneous analytical conclusions due to the variable nature of the data.

What is needed is a definitive answer to the question, "how much data are necessary?", and its corollary "Do I have enough data?". If one knew how to determine the answer to these questions, then the level of confidence in the analytical solutions could be determined. Sediment sampling programs could then be designed to address these concerns in the long view. Existing data sets could be used with a known degree of confidence in the short view.

Report Outline and Organization

The major objective of this research is to offer specific guidance as to how much sediment data are needed to provide the maximum amount of information for use in describing the sediment characteristics of a fluvial system. This is accomplished by introducing a data set upon which the research is based, describing the development of a procedure to meet the objective, and executing said procedure. Findings and results are then presented and conclusions drawn as to the success in meeting the objective.

The report is organized in six chapters as follows. The source and history of the data set used in this research are presented in Chapter 2, along with a discussion as to its quality and applicability to this research. Data base construction, data manipulation, and initial computations necessary to the research are presented in Chapter 3. Statistical analyses and entropy calculations are presented in Chapter 4. Development and description of a procedure for evaluating sediment data sets as to their adequacy for selecting a representative sediment transport function and determining if they are of optimum length is presented in Chapter 5. Chapter 6 contains conclusions as to the usefulness of the procedure, examples of potential applications for the procedure and recommendations for additional research.

2 Research Data

Background

General

The St. Francis River Basin, located in southeast Missouri and eastern Arkansas, in the early 1900's was a vast expanse of bottom land hardwoods and poorly drained, swampy areas. In 1906, a report was published (USACE, 1906) that outlined a plan for drainage of this region and conversion to cropland. In general, the plan and its later revisions called for construction of a flood control reservoir in the upper basin. The remainder of the plan called for massive channelization of the tributaries of the St. Francis River, construction of a levied floodway along the course of the river, and realignment of the river itself. The present day St. Francis River basin drains 5,159 square miles. The basin is about 215 miles long and has a maximum width of 53 miles. The basin slopes vary from 3 feet per mile in the upper basin to 0.5 feet per mile in the lower basin. The bed material is largely sand with an average grain size of 1.0 millimeter in diameter.. As called for in the various plans, the basin has been highly developed hydraulically with structural features including a dam, siphons, inverted siphons, levied flood ways, channel cutoffs, extensive drainage of wetlands along its tributaries and improved channel reaches (USACE 1985). The reservoir, Wappapello Dam and Lake, controls drainage from 1,310 square miles, or about 25 percent of the basin area.

Sediment Sampling Program

Changing channel conditions and land use during the period 1930-1975 created a highly dynamic river system that was in a constant state of flux and thus a system-wide equilibrium was not possible. As the system sought to reach an new equilibrium condition, numerous sediment-related problems arose. These included but were not limited to scour holes at bridges, bank failures, unraveling of tributary channels, excessive channel sedimentation, and overbank deposition of sediments. In order to assist in operating and maintaining this complex network of hydraulic works, the United States Army Corps of Engineers, Memphis District decided to enter into an agreement with the U.S. Geological Survey (USGS) to collect sediment and water quality data at various sites within the basin.

In 1977, the U.S. Army Engineer District, Memphis Hydraulics Branch proposed a sediment sampling program to create a data base of sufficient depth and breadth to address these myriad sediment problems. The author assisted the Hydraulics Branch Chief in designing the initial sediment sampling program and maintained the records and performed various analyses using the data during the period 1977-1983.

The objective of the sampling program was to collect sufficient data to define the sediment budget for the basin, while providing data necessary for engineering analyses aimed at addressing sediment problems within the basin. Twenty-four sites were originally identified as necessary to define the sediment budget for the basin. Fourteen of these were on the main stem of the St. Francis River or its man-made floodway and the remainder on major tributaries. These were arranged such that important tributary sediment sources could be identified. In addition, sediment transport by reach could be computed from the measurements, depicting areas of likely scour or deposition. The data collected went far beyond the basic sediment data needed to define a crude sediment budget. Both bed material and suspended sediment samples were collected and analyzed. These data provided the necessary detailed input to support accurate regime and sedimentation studies using the data collected. The collection of data at the various sites was to be done, on a cost reimbursable basis, by the U.S. Geological Survey office in Little Rock, AR. The cost for data collection at each site averaged $5,000 for a year or about $420 for each measurement. The program was initiated in October, 1977 and data were collected on a water-year basis, that is, from October through the following September. The original 24 site locations are shown in Figure 1.

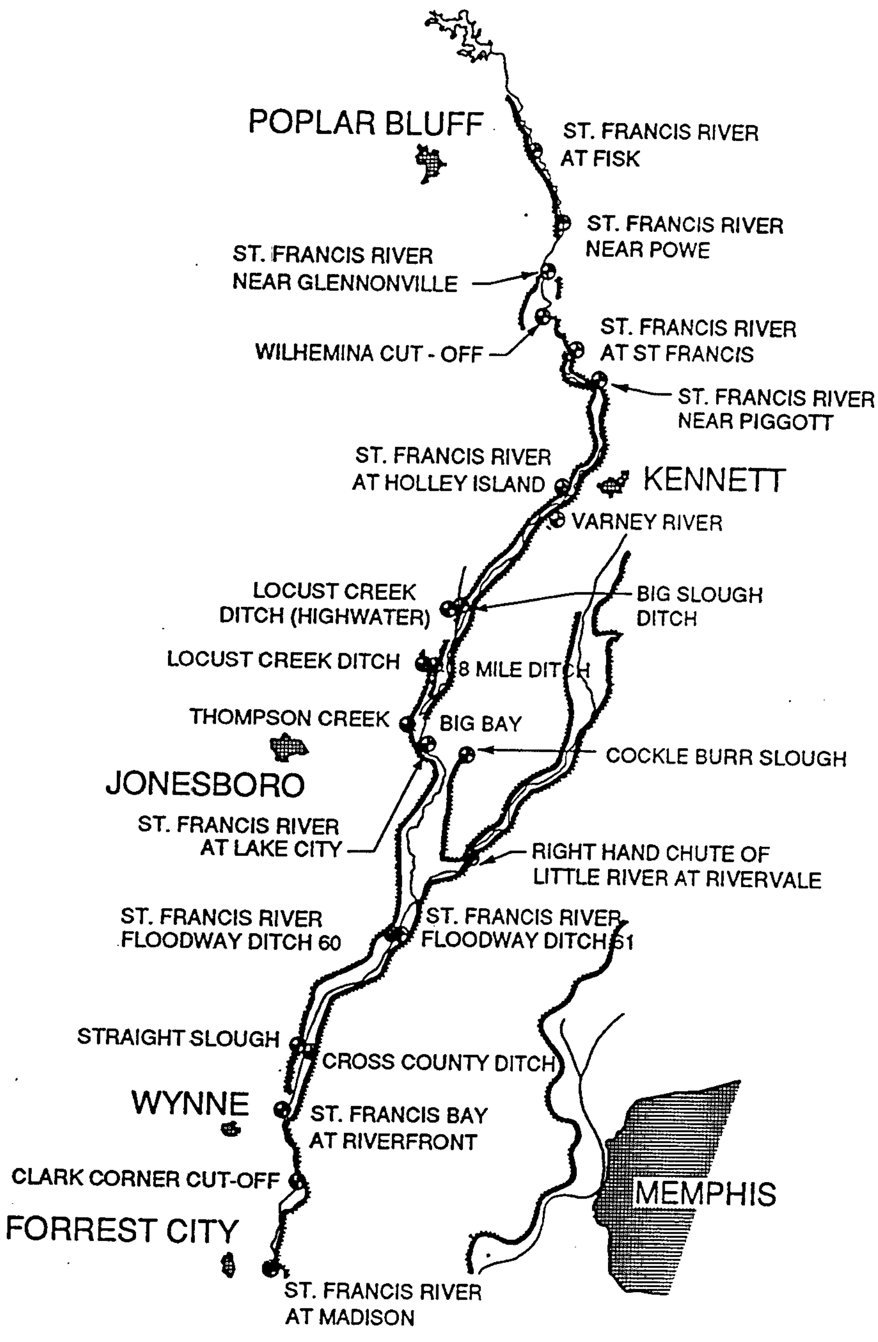

Figure 1. Original 24 sediment sampling stations, 1977

Previous uses of these data include but are not limited to providing boundary conditions for sediment analyses; looking at comparative transport rates for different reaches of the stream system; to investigate sediment contributions from the various tributaries; and to address claims of sand deposition on farm lands.

Sampling Method

The Equal Transit Rate (ETR) method was used to collect the samples. In this method, samples are obtained at equally spaced verticals across the stream. The sampler is lowered and raised at a constant rate. Since the vertical velocity distribution is not uniform, the sample obtained in this manner is quantitatively weighted according to the velocity through which it passes. Such a sample is considered to be discharge weighted because with a uniform transit rate each increment of velocity or discharge in the vertical is given the same amount of time to enter the sampler. This equal spacing between verticals and equal transit rate, both up and down in all verticals, yields a gross sample proportional to the total stream flow (Guy and Norman 1970). The number of verticals sampled varied from station to station and even at a given station with varying discharge; however, the number of verticals was typically near twenty. This is noted as adequate for most all streams (Guy and Norman, 1970). In this method, the transit rate for the sampling bottle is set by the vertical with the highest discharge. The round trip is timed so that the sample bottle is just filled at the end of the upward trip. The samples were composited to produce a single suspended sediment concentration and material for a suspended sediment sample grain size distribution curve. Likewise, bed material samples were collected at the verticals and composited to produce one sample for which a bed material grain size distribution curve was developed.

Discharge measurements were made in conjunction with the collection of the sediment samples. These measurements were primarily made by the USGS. At seven of the 24 stations, the Corps of Engineers were responsible for the discharge measurements and continue to do so. The USGS timed their sampling to coincide with the discharge measurement dates at these seven locations.

Data Collected

At each station the following 37 articles of data were noted, collected or computed;

* Measurement number
* Individual making computations
* Individual checking computations

* Station number
* Date
* Party members
* Width of stream
* Area of flow
* Average velocity
* Gage height
* Discharge
* Method of measuring velocity (either 0.6 depth or 0.2 and 0.8 averaged)
* Number of verticals
* Gage change during measurement
* Meter data (Type, number coefficients etc.)
* Method of sampling (wading, boat, etc.)
* Gage readings
* Rating for measurement
* Flow conditions
* Weather
* Air temperature
* Water temperature
* Flow control
* Whether or not overbank flow was present
* Remarks by party

* Width of vertical
* Depth at vertical
* Velocity observation depth
* Meter revolutions
* Time for revolutions
* Velocity at measurement point
* Mean velocity in vertical
* Adjustments for horizontal angle of meter line
* Area in vertical
* Discharge in vertical
* Suspended sediment gradation
* Bed material gradation

Laboratory Data Analysis

The data collected were sent to a USGS laboratory for analysis. These analyses yielded:

* Suspended sediment concentration, in milligrams per liter or parts per million (PPM)

* Suspended sediment discharge in tons per day
* Suspended sediment diameters (using the grade scale proposed by the American Geophysical Union (Lane, 1947))
* Bed sediment diameters (Lane, 1947)

The percent of the sample contained in each size class was determined using sieve screens for the early data and by use of a Visual Accumulation Tube (VAT) shortly after sampling began. These were the methods from which grain size distributions were determined for each bed and suspended sediment sample. The sieve data particle sizes were referred to as sieve diameter whereas the VAT data particle sizes were referred to as fall diameter. These data are presented in Appendix A under the sample SAS output. The following code was used since the software used would not allow a numerical designation of a variable.

Suspended sediment size, determined on the basis of seive diameter.

SSSA = 2.0 mm

SSSB = 1.0 mm

SSSC = 0.5 mm

SSSD = 0.25 mm

SSSE = 0.125 mm

SSSF = 0.0625 mm

Suspended sediment size, determined on the basis of fall diameter.

SSFA = 2.0 mm

SSFB = 1.0 mm

SSFC = 0.5 mm

SSFD = 0.25 mm

SSFE = 0.125 mm

SSFF = 0.0625 mm

Bed sediment size, determined on the basis of seive diameter.

BMSA = 32.0 mm

BMSB = 16.0 mm

BMSC = 8.0 mm

BMSD = 4.0 mm

BMSE = 2.0 mm

BMSF = 1.0 mm

BMSG = 0.5 mm

BMSH = 0.25 mm

BMSI = 0.125 mm

BMSJ = 0.0625 mm

Bed sediment size, determined on the basis of fall diameter.

BMFA = 2.0 mm

BMFB = 1.0 mm

BMFC = 0.5 mm

BMFD = 0.25 mm

BMFE = 0.125 mm

BMFF = 0.0625 mm

Data Selection

The data set collected for use in this research consisted of all sediment data collected in the St. Francis River Basin for Water years 1978-1988 inclusive. This extensive data set was analyzed to determine how much of the data set could or should be included in the analysis. Criteria were established as follows;

(1) The stations selected should be representative of different flow regimes so that relationships developed would not be station specific. Ideally, there should be at least one station from the upper basin, one from the middle basin, and one from the lower basin.

(2) The flow should be largely confined to the main channel. Sediment samples were composited at the stations and one analysis performed. Limiting the stations to ones that had main channel flow only would remove potential bias introduced by a large number of overbank samples being added to the composite sediment samples.

(3) Tributary stations were not considered. These records were suspect due to influences of backwater from the St. Francis and often very low or no flow was recorded for these stations.

(4) It must be possible to compute any needed variables, notably the slope, for any station selected.

(5) The record should extend for the entire eleven years.

The original twenty-four data collection stations' identification numbers, names, frequency and chronology of sampling, and latitude - longitude coordinates are given in Table 1. It can be seen from Table 1 that beginning with water year 1983, the data collection program began a series of modifications. In this year, four stations located on tributaries were deleted due to poor location or the fact that their contributing basins were of such a size that the monthly collection schedule typically recorded "no flow". Fifteen stations were modified such that data were collected only during the months of November through June. Only five of the original stations were continued as originally conceived with monthly collection of data. These decisions were economically driven as the cost of the sampling program was under scrutiny by upper management. Again, beginning with water year 1985, the data collection program was further modified for economic considerations. Five more stations were deleted, four on tributaries and one on the main stem of the St. Francis River.

Based on the above selection criteria, a station-by-station analysis was conducted. Criteria (3) and (5) eliminated 11 stations (stations 4,8,9,11,12,13,14,15,16,17,23). Criteria (2) eliminated an additional five stations (6,7,10,18,19). This left eight possible stations which, unfortunately, were located in two clusters, one in the upper-middle portion of the basin (stations 24,22,21,20) and one in the lower portion of the basin (stations 1,2,3,5). Two stations were selected from the upper grouping. Fisk was a good selection as the uppermost station in the basin. It had a good, stable cross section, little overbank flow and the necessary slope calculations could be made using the Glennonville station. Fisk was thus selected for analysis. Stations 20,21 and 22 are located on a reach

Table 1
Data Station Identification, Chronology and Location, St. Francis River Basin, MO. & AR.

		Water Year/ # Samples per Water Year			
CE ID	USGS ID	78	83	85	Latitude/Longitude
1	07040000 St. Fr. R.				35 46' 50"
	@ Madison, AR.	12	12	12	90 12' 80"
2	07047904 Clark Corner				35 08' 41"
	Cutoff nr. Colt, AR.	12	8	8	90 39' 23"
3	07047900 St. Fr. Bay				35 15' 34"
	@ Riverfront, AR.	12	12	12	90 40' 48"
4	07047882 Straight Slough				35 21' 45"
	nr. Birdeye, AR.	12	8	—	90 39' 26"
5	07047815 Cross County				35 21' 38"
	Ditch nr. Birdeye, AR.	12	8	8	90 39' 00"
6 & 7	07047810 St. FR. R.				35 32' 15"
	nr. Marked Tree AR.	12	8	8	90 29' 05"
8	07046600 Rt. Hand Chute				35 40" 20"
	Little R. @ Rivervale, AR.	12	12	12	90 29' 12"
9	07040496 Cockle Burr				35 51' 39"
	Slough nr. Monette, AR.	12	8	8	90 19' 49"
10	07040450 St. Fr. R.				35 49' 16"
	@ Lake City, AR.	12	12	12	90 25' 56"
11	07040440 Thompson CR.				35 52' 11"
	nr. Lester, AR.	12	—	—	90 25' 56"
12	07040445 Big Bay Ditch				35 52' 12"
	nr. Lester AR.	12	—	—	90 27' 45"
13	07040428 Locust Cr. Ditch				35 55' 12"
	nr. Dixie, AR.	12	—	—	90 25' 56"
14	07040424 Eight Mile Creek				35 59' 16"
	nr. Paragould, AR.	12	8	—	90 25' 39"

(Continued)

Table 1 (Concluded)					
		Water Year/ # Samples per Water Year			
CE ID	USGS ID	78	83	85	Latitude/Longitude
15	07040424 Locust Cr. Ditch				35 58' 06"
	nr. Paragould, AR.	12	8	—	90 24' 17"
16	07040350 Big Slough Ditch				36 02' 25"
	nr. Paragould, AR.	12	8	—	90 21' 39"
17	07040150 Varney R.				36 08' 20"
	nr. Senath, MO.	12	—	—	90 13' 54"
18	07040130 St. Fr. R.				36 14' 11"
	@ Holly Island, AR.	12	8	8	90 07' 52"
19	07040110 St Fr. R.				36 23' 50"
	nr. Piggott, AR.	12	8	8	90 04' 40"
20	070400100 St. Fr. R.				36 27' 21"
	@ St. Francis, AR.	12	8	12	90 08' 13"
21	07040070 Wilhelmina				36 30' 53"
	Cutoff nr. Campbell, MO.	12	8	8	90 09' 30"
22	07040060 St. Fr. R.				36 39' 38"
	nr. Glennonville, MO.	12	8	8	90 11' 06"
23	07040057 St. Fr. R.				36 39' 38"
	nr. Powe, MO.	12	8	—	90 08' 32"
24	07040000 St. Fr. R.				36 46' 50"
	@ Fisk, MO.	12	12	12	90 12' 08"

of the river approximately 10 miles in length. Due to their proximity, one was deemed representative of this reach of the river. Of the three, station 21, Wilhelmina Cutoff, is the most interesting from a sediment transport aspect. It is located on a man-made reach that reduced the river length by some 7 miles. It experiences very high rates of sediment transport and thus would provide a severe test for any method developed in the basin. Slope calculation could be made using station 22 observations. Therefore, Wilhelmina was also selected for inclusion in the analysis.

Of the lower basin stations, station 1, Madison, is located in the backwater influence of the Mississippi River. It was therefore removed from consideration for selection or use to compute slopes at other stations. The remaining three stations were all equally likely candidates located on a fourteen mile long reach of the river. However, of the three, station 2 offered the largest drainage area, since it was below the large Straight Slough tributary, while the other two were located above this tributary. Therefore, station 2, Clark Corner Cutoff, was chosen. The three stations that were left after consideration of the criteria offered three different cases with which to conduct research. They represented a range of drainage areas from 1,370 square miles for Fisk to over 5,000 square miles at Clark Corner. Peak observed water and sediment discharges range from 30,800 cubic feet per second and 36,341 tons per day, respectively, at Clark Corner to 10,400 cubic feet per second and 1,954 tons per day at Fisk.

In summary, stations 2, (Clark Corner Cutoff near Colt, Arkansas), 21 (Wilhelmina Cutoff near Campbell, Missouri), and 24 (Fisk, Missouri) were selected for detailed analysis. These stations offered varied hydraulic and sediment conditions and very high quality, professionally collected data, with which to perform the research. The station locations are shown in Figure 2.

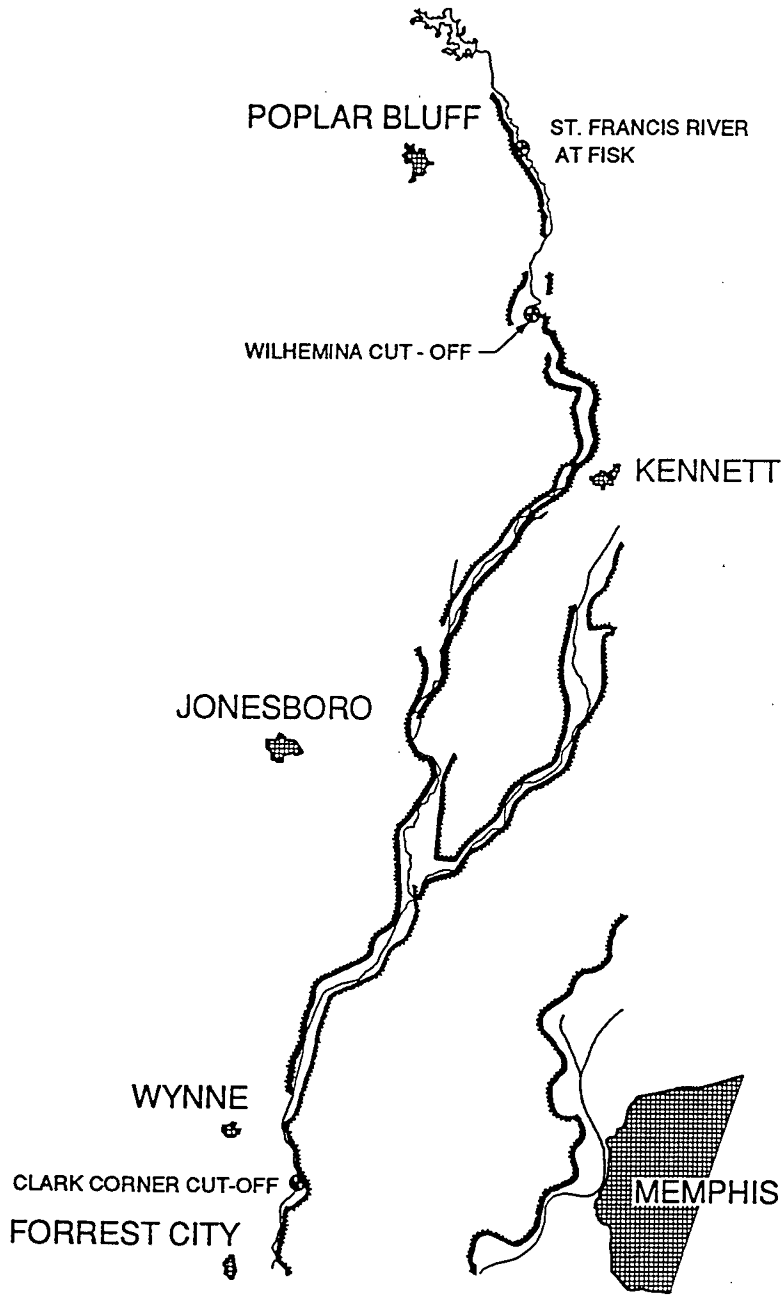

Figure 2. Location of sediment sampling stations used in the analyses

Research Data Base Creation

The data selected for analysis were gathered from several different sources. Some of the data collected were published in standard USGS format (USGS 1977-1988). A sample of these are shown for the Fisk, Missouri, station in Figure 3. While useful, the data in this form would require cumbersome transfer to a data base to allow numerical manipulation. In discussions with the USGS in Little Rock, Arkansas, it was discovered that the data were available in digital format. This format, referred to as 'Flat File Format' by the USGS, contained all the data shown in Figure 3.

Additional data were available on the field data sheets. These sheets are forms filled out by the survey party members on site while actually collecting the data. The information recorded is that described in the 'Data Collected' section above. A copy of a sample field data sheet for the Fisk, Missouri, station is shown in Figure 4. From these sheets, values for the top width of flow, area of flow, average flow velocity and maximum depth of flow were obtained. In addition, average depth was computed by dividing the flow area by the top width. The digital data set was thus augmented by adding these additional values by means of hand editing the files. Additional data were computed as will be discussed in Chapter 3.

ST. FRANCIS RIVER BASIN

07040000 ST. FRANCIS RIVER AT FISK, MO

LOCATION.--Lat 36°46'50", long 90°12'08", in NW 1/4 SW 1/4 sec.28, T.24 N., R.8 E., Butler-Stoddard County line, Hydrologic Unit 08020203, at bridge on U.S. Highway 60, at Fisk, Mo.

PERIOD OF RECORD.--October 1977 to current year.

WATER QUALITY DATA, WATER YEAR OCTOBER 1982 TO SEPTEMBER 1983

DATE	TIME	MEDIUM	AGENCY COLLECTING SAMPLE (CODE NUMBER) (00027)	AGENCY ANALYZING SAMPLE (CODE NUMBER) (00028)	STREAMFLOW, INSTANTANEOUS (CFS) (00061)	SPECIFIC CONDUCTANCE (UMHOS) (00095)	PH (STANDARD UNITS) (00400)	TEMPERATURE (DEG C) (00010)	TRANSPARENCY (SECCHI DISK) (M) (00078)
OCT									
19...	1230	0	80513	80513	335	174	7.7	17.5	.70
NOV									
15...	1400	0	80513	80513	328	172	7.9	9.0	.50
29...	1150	0	80513	80513	1020	182	7.6	8.5	.80
JAN									
10...	1400	0	80513	80513	10400	85	7.0	8.5	.40
FEB									
14...	1250	0	80513	80513	3360	203	7.8	6.5	.90
MAR									
15...	1430	9	80513	80513	1320	204	8.5	12.0	.50
APR									
13...	1630	9	80513	80513	2360	176	8.0	12.0	.80
MAY									
09...	1645	9	80513	80513	7000	108	7.2	17.5	.50
JUN									
14...	0830	9	80513	80513	910	160	7.4	22.0	.40
JUL									
12...	1300	9	80513	80513	178	179	7.7	29.0	.20
AUG									
08...	1230	9	80513	80513	110	223	8.2	28.5	.20
SEP									
13...	1400	9	80513	80513	61	229	8.5	27.0	.20

DATE	TIME	OXYGEN, DISSOLVED (MG/L) (00300)	OXYGEN, DISSOLVED (PERCENT SATURATION) (00301)	BAROMETRIC PRESSURE (MM OF HG) (00025)	SEDIMENT, SUSPENDED (MG/L) (80154)	SEDIMENT, DISCHARGE, SUSPENDED (T/DAY) (80155)	SED. SUSP. FALL DIAM. % FINER THAN .062 MM (70342)	SED. SUSP. FALL DIAM. % FINER THAN .125 MM (70343)	SED. SUSP. FALL DIAM. % FINER THAN .250 MM (70344)
OCT									
19...	1230	7.8	82	760	33	30	95	98	100
NOV									
15...	1400	11.6	101	760	31	27	66	75	94
29...	1150	12.6	108	760	56	154	66	97	99
JAN									
10...	1400	11.2	97	750	38	1070	80	90	95
FEB									
14...	1250	12.6	103	756	49	445	68	76	97
MAR									
15...	1430	10.7	101	750	29	103	97	97	98
APR									
13...	1630	9.3	87	760	85	542	76	90	99
MAY									
09...	1645	9.6	101	760	31	586	78	84	95
JUN									
14...	0830	6.5	75	758	71	174	94	97	100
JUL									
12...	1300	6.4	84	760	58	28	88	89	90
AUG									
08...	1230	7.5	97	757	29	8.6	92	96	100
SEP									
13...	1400	7.9	100	760	26	4.3	97	98	98

Figure 3. Sample of the published USGS data used in the analyses (Continued)

07040000 ST. FRANCIS RIVER AT FISK, MO--CONTINUED

WATER QUALITY DATA, WATER YEAR OCTOBER 1982 TO SEPTEMBER 1983

DATE	TIME	SED. SUSP. FALL DIAM. % FINER THAN .500 MM (70345)	BED MAT. FALL DIAM. % FINER THAN .062 MM (80158)	BED MAT. FALL DIAM. % FINER THAN .125 MM (80159)	BED MAT. FALL DIAM. % FINER THAN .250 MM (80160)	BED MAT. FALL DIAM. % FINER THAN .500 MM (80161)	BED MAT. FALL DIAM. % FINER THAN 1.00 MM (80162)	BED MAT. FALL DIAM. % FINER THAN 2.00 MM (80163)
OCT								
19...	1230	--	2	3	77	99	100	--
NOV								
15...	1400	100	2	2	79	99	100	--
29...	1150	100	3	4	56	98	100	--
JAN								
10...	1400	100	16	27	86	100	--	--
FEB								
14...	1250	100	2	7	83	100	--	--
MAR								
15...	1430	100	3	3	38	97	100	--
APR								
13...	1630	100	2	2	55	98	100	--
MAY								
09...	1645	100	8	8	15	83	100	--
JUN								
14...	0830	--	4	6	55	90	100	--
JUL								
12...	1300	100	4	18	96	99	100	--
AUG								
08...	1230	--	3	19	95	99	100	--
SEP								
13...	1400	100	5	18	94	99	99	100

Figure 3. (Concluded)

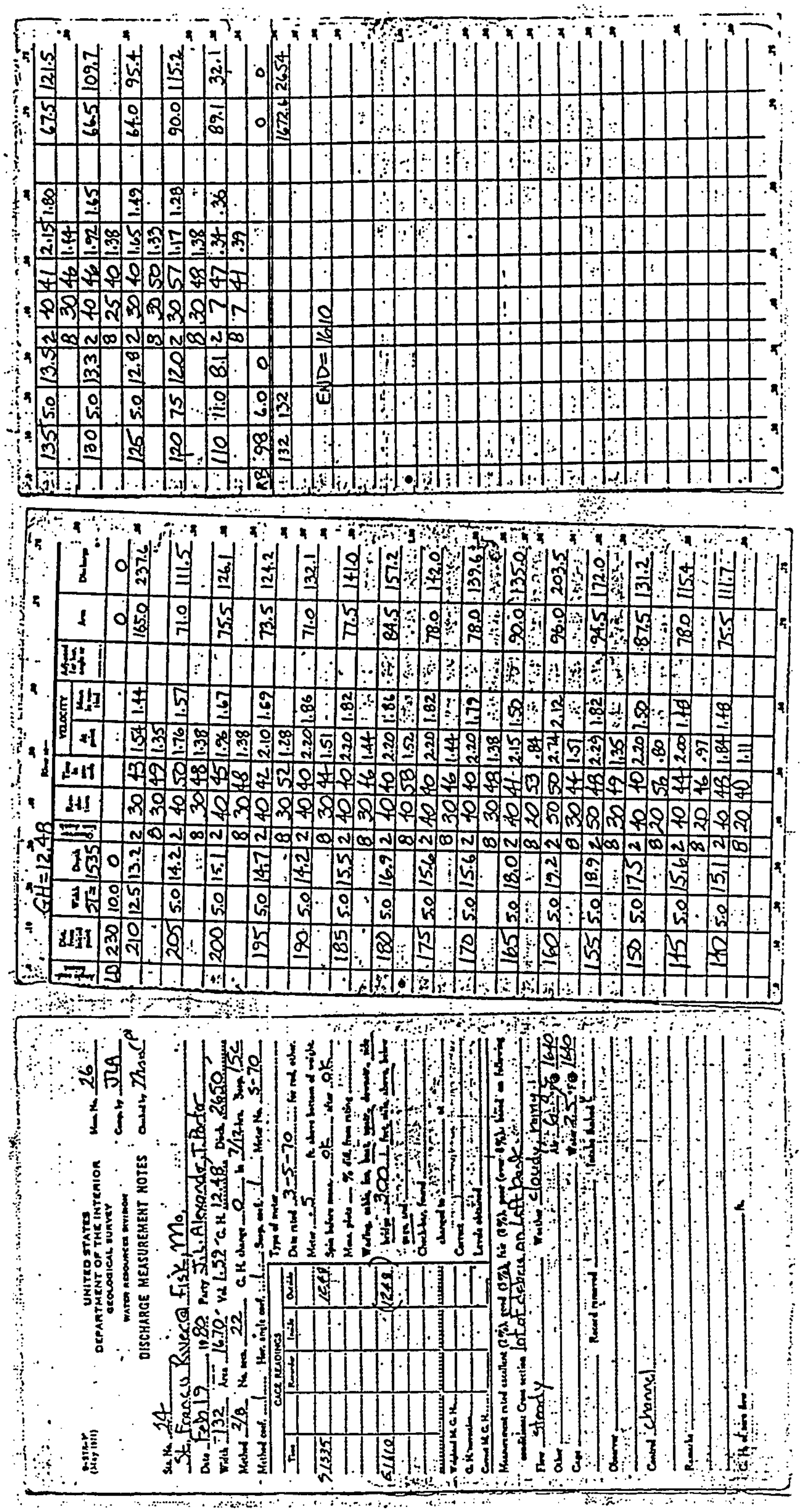

Figure 4. Sample field data sheet

Data Base Operations

In order to provide ease of manipulation and the capability to perform various numerical functions on the data, it was deemed necessary to use a software program or programs that could manipulate the data, perform numerical functions on the data and present the results in tabular and/or graphical form. In the course of the analysis, several programs were ultimately used to accomplish the construction of and operations with the data base. Initially, all of the data were input into the Statistical Analysis Software (SAS) Package developed by the SAS institute, Cary, North Carolina (SAS, 1988). A sample of the output from this software is shown in Appendix A. The data printed in this format was easy to read and reference to dates or other values. While the software contained powerful statistical routines, the software required renewal on an annual basis for continued use. For this reason, other software was used for statistical analyses as discussed below.

SuperCalc4 spreadsheet software (Computer Associates, 1987) developed by Computer Associates, San Jose, California, was used to compute stream slopes for each observation used in the analyses. The gage heights were input for adjacent gages. These were added to the gage zero and the difference divided by the distance between the gages to compute the water surface slope for each observation. The slope could not always be calculated for each raw observation due to missing gage data at either of the two stations used in the computations. Therefore, the total number of observations was reduced for this reason by twenty-five at Fisk, two at Wilhelmina and five at Clark Corner. An example of this output is given in Appendix A.

The U.S. Army Corps of Engineers Hydraulic Design Package for Channels (SAM) (Thomas et al., 1992) was used to compute the sediment transport for the observations. These data then became the basis for additional research as is described in chapter 3. Grain size information on the bed material is required by the SAM program. The sediment samples were either lost or not taken for a number of the observations, rendering sediment transport computations impossible. For this reason, the number of data observations available for analysis was reduced by two at Fisk, two at Wilhelmina and sixteen at Clark Corner. An example of the SAM input and output are included in Appendix A. Table 2 below summarizes the data adjustment made and described above.

Table 2
Data Reduction

Station	Raw Observations	Reduction-Missing Slope	Reduction- Missing Bed Samples	Adjusted Number of Observations
Fisk	128	25	2	101
Wilhelmina	103	0	2	101
Clark	105	5	16	84

STATGRAPHICS software, (Manugistics, 1993) developed by Manugistics, Rockville, Maryland was used for statistical analyses, distribution fitting and plotting of results. The input files for this software were extracted from those used in the SAS software, with observation deleted where no slope or sediment data were available, as discussed above. This software was used to perform the regression and distribution fitting exercises presented in Chapter 4. Many of the figures in this report were developed directly from this software. A sample input file is shown in Appendix A.

Quattro Pro V 6.0, (Wordperfect, 1993) developed by the Novell Applications Group, Wordperfect, Orem, Utah, was used for the entropy calculations presented in Chapter 4 and plotting of certain results. The necessary input was extracted from the other data sources and input in spreadsheet format. Some of the figures in this report were developed directly from this software. A sample input file is shown in Appendix A.

3 Initial Approach to the Problem

Introduction

The first step, after consolidating the data base, was to check the goodness of the samples in the available data. Furthermore, it was decided that the data for the Fisk, Missouri station would be used to develop the initial methodology. This station was selected because it had the narrowest range of water flows and sediment discharge. Subsequent development would proceed in a downstream direction, with ever higher water flows and increasing sediment discharge. None of the data were arbitrarily eliminated as being non-representative, as it was all representative of data sets that might reasonably be expected to be analyzed in the future. Twenty-seven of the total observations at the Fisk Station were eliminated for lack of slope or bed material data as summarized in Table 2. It should be noted that the basin characteristics are sufficiently different from the vicinity of the Fisk station to those at the lower end as to provide a fairly rigorous test of any procedure developed.

Sediment Transport Computations

Computations of sediment transport were necessary for each observation. These would be the basis for determining goodness of the data collected and to assist in determining the number of samples required to adequately describe the sediment transport regime.

Initially, the sediment transport computations were made for each observation using the CORP system (Jones, 1977). However, this method required input for each individual observation and for each transport function investigated. In addition to gathering the individual hydraulic input parameters, such as average velocity, kinematic viscosity, depth and width of flow, volume of flow, etc., detailed sediment data were also required. These were in the form of either the d_{50} or the d_{65} bed material grain size. To determine these values, it was necessary to plot the bed material data as a grain size distribution curve. An example of this is shown in Figure 5. This was clearly too slow and cumbersome for the large number of solutions needed. To address this problem, the SAM system (Thomas et al., 1992) mentioned above was used. The SAM system allows simultaneous computation of sediment transport using thirteen sediment transport functions. These include functions developed by Toffaleti (Toffaleti, 1969); Yang (Yang, 1973); Ackers-White (Ackers and White, 1973); Colby (Colby, 1964); Toffaleti-Schoklitsch (in preparation); Meyer-Peter Muller (Meyer-Peter and Muller, 1948);

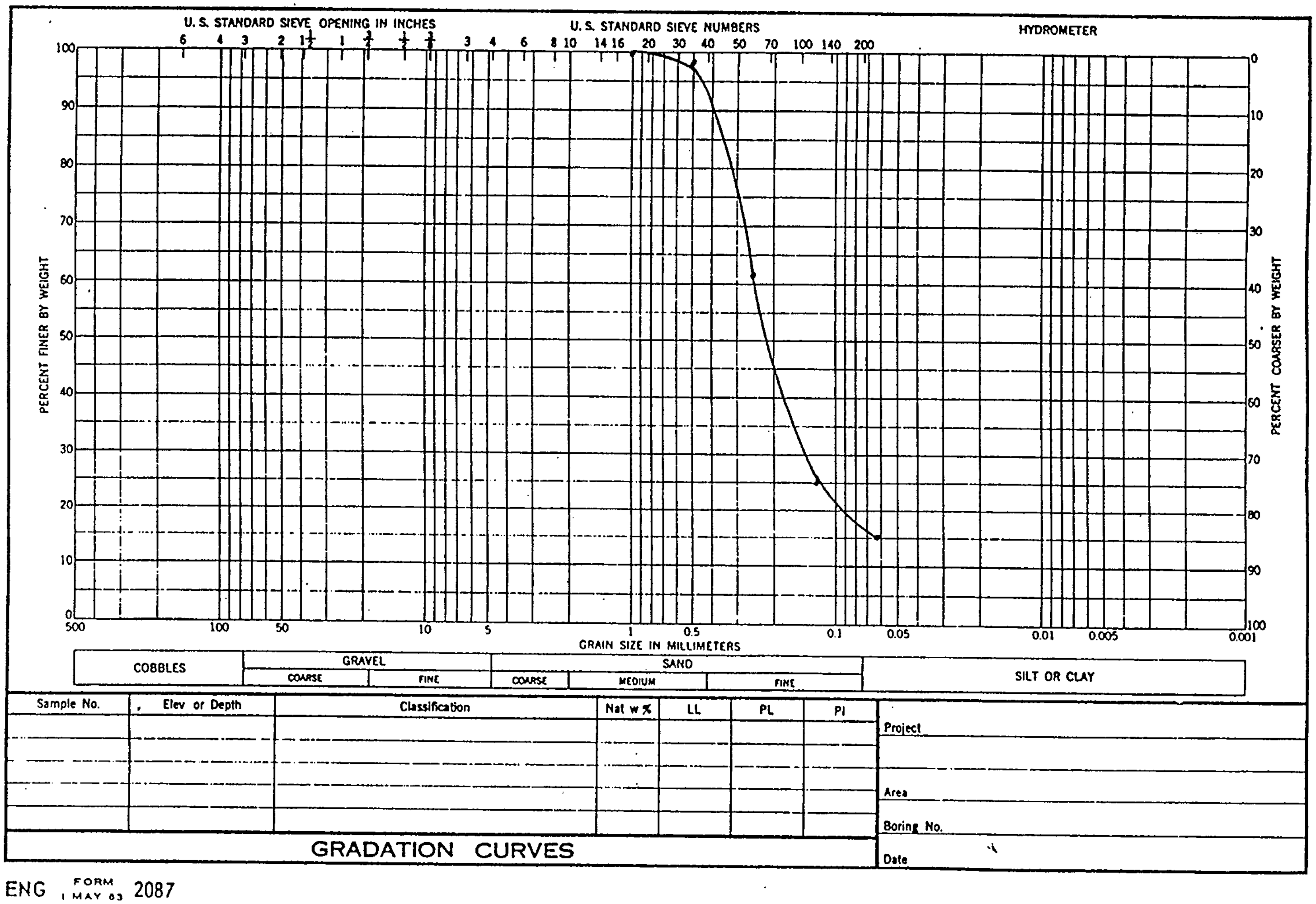

Figure 5. Sample bed material grain size distribution curve, 20 Nov 1979, Fisk, MO

Brownlie (Brownlie, 1981); Toffaleti-Meyer-Peter Muller (in preparation); Laursen-Madden (Madden, 1985); Laursen-Copeland (Copeland and Thomas, 1989). There were also three modified transport functions. Those that used only the single d_{50} grain size in the computations are denoted "d_{50}." These include Yang, Ackers-White and the Meyer-Peter Muller equations. The other versions of these transport functions have been modified by The U. S. Army Engineer Waterways Experiment Station (WES) Hydraulics Laboratory (Thomas et al., 1992) to compute sediment transport based on grain size class. These versions are denoted "HEC-6 Versions".

Calculations for all of the above functions are made from a common data base. Sample input is shown in Appendix A. Thomas et al. have offered the following summary of the sediment transport equations and their capabilities, which is paraphrased herein. While varying significantly in their individual approach, all of the equations share a common functional form. This is given as

$$Gs_i = f(\, V, D, S, W, d_r, d_i, PI_i, s_s, T, s_f)$$

where

V = flow velocity

D = water depth

S = energy slope

W = with of the portion of the channel cross section which is transporting bed material sediment

d_r = representative particle size for the sediment mixture

d_i = sediment particle size in class I

PI_i = percentage of total sediment particles in size class I

s_s = specific gravity of the sediment particles

T = temperature of the fluid

s_f = specific gravity of the fluid

All of the sediment transport functions listed above were originally supported in the HEC-6 software program (HEC, 1976) with the exception of the Brownlie equation. A brief description of each equation follows.

Ackers-White This is a single grain size function for sand bed streams. There is also a version which computes sediment transport by size class using the median grain size for the class as the single grain size. The various classes are then totaled to arrive at an overall transport value. This multiple grain size version is the "HEC-6 version".

Brownlie This is a single grain size function for sand transport. It is presented in greater detail in Chapter 1 of this report.

Colby This is a single grain size function for sand transport in streams and small rivers. It, too, is covered in more detail in Chapter 1.

Laursen (Madden) This is a multiple grain size function for sand bed transport. It has also been used for mixtures of sand and gravel.

Laursen (Copeland) This is a modification of the Laursen (Madden) equation.

Meyer-Peter and Muller This is a multiple grain size function for gravel bed rivers.

Toffaleti This is a multiple grain size function for sand bed rivers.

Yang This is a single size function for sand transport in streams and small rivers.

See Chapter 1 for a more detailed explanation.

Quoting from the SAM user's manual (Thomas et al., 1992), "This is not an exhaustive list of transport functions. They were selected from the literature based on experience. It does not imply that those not selected are deficient. The objective was to provide designers with a'few' acceptable methods which could be supported for their use. The criteria for selection are

a. To cover a broad range of particle sizes.

b. To cover a broad range of hydraulic conditions.

c. To calculate sediment transport by partitioning the mixture into size classes and summing the rate of each to get the total except when d_{50} functions are requested.

d. To have a history of being reliable when used within the range of data for which each was calibrated."

Together, this group of functions represents a very comprehensive collection for the prediction of sediment transport, especially for sand bed streams. After careful analysis of the initial results from the SAM computer runs, 10 of the 13 transport functions were used in the analyses. The two Meyer-Peter and Muller functions and the hybrid Toffaleti-Meyer-Peter and Muller function were not used. The Meyer-Peter and Muller function is basically intended for use on streams with no appreciable suspended sediment load (Vanoni, 1975). Therefore, this function would not be expected to perform well on the St. Francis River which is predominantly a sand bed stream with a high suspended sediment load and was removed from further consideration. The Toffaleti-Meyer-Peter and Muller, which uses the higher sediment transport value calculated by the two methods, should default to the values of the Toffaleti function for most of the St. Francis calculations. Since the Toffaleti transport function is included in the analysis, this hybrid function was also not used. The Toffaleti-Schoklitsch transport function also combines a function intended for high suspended loads with that of one intended for bed load transport (Vannoni, 1975; Shultis, 1935). This was the one hybrid function retained, just for comparison to the basic Toffaleti function.

An input file for the SAM software was prepared that represented all the Fisk data. Most of the functions actually call for the slope of the energy grade line as an input parameter. However, for a river such as the St. Francis, the assumption that the water surface slope and the slope of the energy grade line are equivalent is valid (Chow, 1959). This is so due to the relatively gentle slopes and low energies involved. Therefore, the previously computed water surface slopes were input for the slope values. It was also necessary to convert the temperature values from degrees Celsius to degrees Fahrenheit. This had been done with the SAS software and these values were input. Bed material data were input as the discrete values shown in Appendix A. From these, the SAM software developed the grain size distribution curves and extracted the necessary grain size information for each transport function. An example of the input to and output from the SAM software is included in Appendix A.

The SAM software was then used to calculate sediment transport values using the 10 selected sediment transport functions. Values of bed material sediment transport are presented in tons per day. This is consistent with the values reported in the USGS field measurements. These values are shown in Table 3. The procedure was repeated for the Wilhelmina Cutoff and Clark Corner Cutoff stations. These results are tabulated in Tables 4 and 5, respectively. The following abbreviations are used for the column headings.

OBS QS - Measured bed material discharge, computed by multiplying the total measured load (which included bed material load and wash load) by 1 minus the percent of suspended sediment smaller than 0.062 mm. Material smaller than this is in the silt-clay class of particle sizes which largely constitute the wash load and non-cohesive transport functions are not applicable to these size classes of particles.

TOFF - Sediment transport calculated with the Toffaleti transport function.

YNG6 - WES modified version of the Yang sediment transport function. It calculates sediment transport by size class and sums the values for size classes present.

AWH6 - WES modified version of the Ackers-White sediment transport function. It calculates sediment transport by size class and sums the values for size classes present.

CBY6 - WES modified version of the Colby sediment transport function. It calculates sediment transport by size class and sums the values for size classes present.

TFSH - A hybrid sediment transport function developed by the WES. It calculates sediment transport by both the Toffaleti and Schoklitsch methods and uses the greater value.

BRN - Sediment transport calculated with the Brownlie transport function.

LSMD - Sediment transport calculated with the Laursen-Madden transport function.

LSCP - Sediment transport calculated with the Laursen-Copeland transport function.

YG50 - Sediment transport calculated with the Yang single grain size transport function.

AW50 - Sediment transport calculated with the Ackers-White single grain size transport function.

Table 3
Observed Water and Sediment Discharge and Computed Bed Material sediment Discharge using 10 Different Transport Functions at the Fisk, Mo. Sampling Station

Water Flow	OBS Qs	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
303	7.38	0	7	11	0	0	2	0	4	7	4
925	77.12	8	92	1169	0	39	18	0	82	69	123
2860	1133.23	79	350	11228	130	190	186	1057	245	318	393
654	27.34	2	24	41	96	3	8	17	18	22	12
5600	1172.10	1286	3853	360742	391	2304	1350	15170	2246	3116	13580
1250	474.59	14	83	165	0	31	37	82	38	78	46
352	147.3	1	10	14	0	1	2	0	5	10	5
38	3.44	0	0	0	0	0	0	0	0	0	0
433	45.42	1	13	9	0	2	5	1	5	15	7
475	112.35	0	4	9	0	0	2	0	3	18	78
195	30.11	0	2	0	0	0	0	0	3	2	0
128	13.25	0	0	0	0	0	0	0	0	0	0
463	60.78	1	15	50	0	3	6	0	13	18	15
1740	172.51	115	435	28222	42	217	219	2867	670	633	13468
5160	345.37	248	764	8666	235	523	622	1411	350	1012	1759
8320	840.38	1418	2024	2885	1353	2047	1415	2808	878	1954	1982
3550	68.44	691	754	11805	159	900	947	2636	543	1932	32890
168	1.36	0	2	3	0	0	0	0	1	8	43
75	1.29	0	0	0	0	0	0	0	0	0	0
101	3.87	0	0	0	0	0	0	0	0	0	0
65	1.37	0	0	0	0	0	0	0	0	0	0
303	7.66	0	4	10	0	0	0	0	2	4	2
2060	24.92	116	422	24846	97	238	221	2236	447	446	1800
608	3.55	2	31	566	0	9	7	0	25	77	1558
1270	5.35	23	115	482	123	59	48	139	68	112	143
1780	13.41	28	188	557	89	108	79	133	51	177	127
1140	18.53	7	66	384	0	40	47	0	21	192	2191
114	0.2	0	1	0	0	0	0	0	2	2	0
121	1.9	0	1	1	0	0	0	0	0	1	1
46	0.56	0	0	0	0	0	0	0	0	0	0
100	1.5	0	1	1	0	0	0	0	0	1	0
99	1.12	0	1	1	0	0	0	0	1	1	1
227	3.44	0	5	6	0	0	0	0	3	4	2
1720	20.06	14	77	454	19	36	391	43	42	11675	****
88	1.81	0	1	1	0	0	0	0	1	2	2
558	9.01	1	17	56	0	2	4	18	12	16	8
378	8.92	0	9	37	0	1	1	0	4	1	10
130	1.41	0	1	1	0	0	0	0	0	1	1
3030	38.29	359	576	6196	171	537	480	1922	395	676	1231
2860	23.55	235	446	882	153	368	276	598	176	427	257
2460	224.43	424	534	455	205	597	371	395	167	532	377
252	2.1	0	5	3	0	0	1	0	2	5	2
1730	109.44	80	177	568	38	143	178	257	90	276	474

(Sheet 1 of 3)

Table 3 (Continued)

Water Flow	OBS Qs	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
101	1.30	1	2	1	19	1	5	6	13	4	1
197	1.72	0	4	3	0	0	0	0	2	4	2
302	1.17	0	5	18	0	0	0	0	2	6	3
6150	232.5	691	1345	2215	1068	1112	854	2289	658	1217	1128
3650	204.49	1365	923	4481	757	1615	764	2414	725	899	1557
1170	32.38	232	167	312	239	256	179	407	297	162	220
133	2.2	0	1	1	0	0	0	0	1	1	0
2160	57.15	222	315	317	107	319	240	212	134	321	302
115	0.4	4	4	3	5	4	5	18	22	5	3
123	1.26	0	0	0	0	0	0	0	0	0	0
2530	81.97	191	401	632	121	339	257	360	146	398	405
328	9.33	2	10	7	0	2	3	0	8	10	7
1020	52.43	20	74	137	27	32	43	73	58	69	63
10400	213.40	875	2403	84699	579	1648	1504	8398	1484	2596	6398
3360	142.25	176	691	28906	135	414	388	2300	429	744	2040
1320	3.10	38	116	113	70	56	72	92	68	108	75
2360	129.99	79	293	348	95	184	165	202	112	282	244
910	128.9	16	57	62	64	20	35	34	34	57	38
1770	13.12	112	276	2699	56	206	171	992	210	292	546
4200	394.29	440	1019	23334	638	755	620	2813	666	995	2004
876	3.57	6	23	23	22	6	18	45	33	23	14
2660	18.39	268	446	766	474	392	327	865	346	418	490
3200	147.74	0	0	0	0	0	64	0	0	357	21
3500	45.4	632	702	1320	429	841	535	967	335	685	668
956	37.58	29	71	71	28	34	52	54	52	70	55
252	0.73	1	6	3	0	1	2	2	5	6	2
3950	77.64	555	661	2663	627	741	524	1531	495	644	1114
3830	148.91	640	813	1409	549	863	624	1520	530	773	883
7980	555.03	1973	2620	167926	1589	2543	1806	8834	2125	2178	2417
1130	37.4	54	29	132	21	57	0	635	254	0	0
4790	88.72	447	387	746	285	548	0	3357	1116	0	0
7410	270.10	1432	1743	3273	1127	1857	1665	3977	2598	1976	1361
2910	26.71	364	424	1041	257	475	377	718	282	476	374
3320	377.56	646	704	1136	330	872	528	861	286	698	732
3630	104.28	487	740	2464	517	708	524	1286	405	703	705
4410	599.72	381	715	900	408	545	617	992	413	773	579
2510	104.1	233	325	2119	270	314	328	1095	881	350	399
1710	14.22	137	217	384	213	183	167	537	280	210	309
3210	75.49	293	434	1358	347	419	332	888	331	433	613
1960	21.43	177	214	284	171	211	193	283	197	205	218
440	7.78	7	18	17	9	7	15	24	28	19	15
2920	276.73	539	545	521	428	675	463	432	255	555	431
47	0.39	0	0	0	0	0	0	0	0	0	0
1320	29	78	134	179	123	96	106	256	179	119	122
548	0.62	0	1	1	0	0	1	1	1	1	1
1340	23.97	78	149	237	141	106	108	353	211	144	193
1710	36.7	147	209	434	142	184	169	409	212	194	201

(Sheet 2 of 3)

Table 3 (Concluded)

Water Flow	OBS Qs	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
608	4.60	20	38	40	33	20	35	54	59	39	37
86	30.50	0	1	0	0	0	0	0	0	1	0
85	2.22	0	0	0	0	0	0	1	1	0	0
60	0.01	1	1	0	11	1	2	10	18	1	0
1010	4.4	44	80	92	80	49	67	131	121	70	66
4260	72.35	518	608	1261	581	658	563	1584	619	609	641
2070	36.89	569	314	17007	59	625	0	13566	4436	0	0
2200	25.19	299	314	1811	230	361	290	1150	436	310	386
3150	42.53	751	583	1348	449	888	537	1056	453	575	614
310	13.89	1	7	4	0	1	4	2	8	8	4
194	0.53	0	3	1	0	0	1	0	3	3	1

(Sheet 3 of 3)

Table 4

Observed Water and Sediment Discharge and Computed Bed Material Sediment Discharge using 10 Different Transport Functions for the Wilhelmina Cutoff, Mo. Sampling Station

FLOW	QS	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
1470	88.73	1455	3861	22002	858	2968	1474	6326	1629	3819	5153
4070	2781.43	4981	33981	6134644	4565	13836	9502	57373	10478	32032	90340
1220	370.0	654	2849	37495	460	1922	827	5144	1340	2715	3838
2040	6761.62	1511	5615	83972	536	3757	1754	9593	1681	4814	5243
580	686.01	32	1031	77051	79	730	116	809	320	928	1677
226	66.18	4	109	87	0	158	16	5	15	112	47
1300	130.99	41	434	572	37	484	119	202	71	477	242
140	193	0	88	175	0	323	6	0	4	136	65
245	44.09	215	324	323	80	405	141	352	221	315	209
290	1096	887	1256	2008	564	1394	505	1756	2239	1084	865
591	180.71	485	2528	41199	187	1757	559	4521	1214	2285	2558
2030	667.58	132	4375	1299697	30	2310	738	3640	729	5085	33614
2720	433.00	2263	13765	6445910	398	5379	2557	27281	7129	10553	49374
6920	1068.00	9153	22968	3587715	1397	12668	6460	71283	16025	19906	403569
9110	7762.00	7627	29143	2646836	2058	13658	9223	64367	10634	22654	75242
4600	578.00	2218	5394	48750	853	4521	2290	9495	1533	5091	6662
272	114.00	132	309	204	43	351	122	183	114	314	206
2820	3962.00	6373	7186	13673	4525	7948	5556	9912	6274	7179	10170
220	8.0	1	83	39	0	153	9	0	6	88	30
169	7.84	151	206	161	124	237	103	218	261	209	162
110	61.00	49	105	72	52	80	46	135	162	105	67
478	317.00	587	755	732	388	926	334	954	815	755	712
1640	1213.00	2940	7432	86374	2110	5207	2370	15354	4902	7320	16362
672	255.00	323	1459	17154	239	1006	382	2786	748	1369	2092
1700	485.00	1566	5153	59893	743	3804	1565	8495	1858	5030	7450
2290	849.00	4810	8113	19994	3160	7124	4318	12257	5462	7948	10912
1120	403.00	1463	3100	6066	832	2592	1583	4184	1420	3288	3692
170	9.22	1	41	16	0	71	3	0	3	43	16
222	1.32	139	260	199	51	309	110	204	137	265	178
1230	3.06	1	30	11	0	47	3	0	4	37	9
127	4.4	16	84	45	0	65	25	29	49	85	46
109	1.21	0	17	19	0	31	0	0	2	20	6
267	9.18	73	306	246	63	254	94	343	229	309	236
571	790.00	1497	3657	6693	1087	2622	1302	6184	2644	3653	6217
228	14.00	25	246	232	384	191	56	239	150	244	199
658	5.90	824	1572	2216	474	1491	596	2592	957	1612	2108
598	40.00	708	1291	1600	382	1288	513	1912	834	1292	1414
501	13.00	576	929	831	258	1050	430	1010	560	950	781
2790	393.00	2261	5317	6624	1288	4359	2416	7467	1775	5404	6596
3230	342.0	1887	6485	9044	876	4828	2780	7001	1279	6590	5180
447	4.05	284	590	388	109	686	242	383	248	602	378
435	485.00	740	846	2102	217	1111	323	1779	833	722	684
1490	116.00	2758	4345	7556	1556	4317	2209	5961	2836	4330	4906
186	1.82	79	213	164	51	206	78	190	150	216	161

(Sheet 1 of 3)

Table 4 (Continued)

FLOW	QS	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
202	4.20	79	198	148	75	170	80	212	218	199	142
379	3.50	10	250	194	0	250	36	0	77	261	189
6700	1505.00	3677	11569	207599	2821	7155	4767	22608	3506	11269	24695
4550	673.00	2588	8385	11744	1621	5635	3638	12133	2001	8371	10826
1240	588.0	2378	3502	4778	1469	3554	1787	5080	2463	3555	4820
316	14.00	39	242	147	432	247	72	64	69	242	142
1950	408.00	476	168	381	1761	476	445	222	1123	171	387
1140	76.00	981	2444	1862	363	2427	959	2267	743	2489	1820
2370	176.00	2157	6503	72601	526	4698	1966	12958	2234	5225	6061
338	7.28	29	376	4347	102	271	66	560	176	324	360
1760	105.00	1544	3227	5180	890	2878	1240	5553	1526	3272	4969
9820	6508.00	7995	23584	599086	8886	13142	12054	49003	9553	24010	60325
3460	550.00	1997	5363	11904	1330	3973	2006	10005	1766	5356	11346
1550	476.00	1250	3181	4375	719	2619	1245	4734	1277	3146	3692
1910	152.00	890	3235	4122	414	2518	1171	4001	786	3484	4196
10200	2160.00	6515	21190	110754	5422	12075	10989	33597	5317	21146	31366
1320	134.00	447	1372	1651	120	1261	538	1154	374	1333	535
1250	199.00	1224	2124	2511	617	2167	931	2873	1025	2119	2366
5020	240	3126	7468	568638	2234	5233	2831	18917	3661	6996	20866
6340	906.00	2429	6065	10785	1632	4479	3090	9998	1927	6218	8817
2870	828.00	3423	5728	37039	2528	5061	2798	12055	3979	5620	10275
3780	389.00	1954	5150	6670	1097	4024	2315	7051	1403	5205	6046
3570	456.00	1943	5524	23559	863	4245	2322	7742	1392	5422	5705
1120	176.00	1245	1337	1358	712	1776	838	1318	981	1360	1331
331	10.00	186	286	207	82	348	143	205	148	297	209
11900	14342.0	15847	48724	1306142	18243	24482	24599	98288	21970	47578	143098
4420	212.00	2485	3520	30947	1513	3618	1827	7985	1850	3421	6623
10200	3824.00	6008	20769	1839976	6622	10772	9070	48244	7409	21397	80212
3210	349.0	2728	6396	20951	2330	4513	2584	15362	3366	6452	18662
5930	357.00	2521	5279	9965	1693	4269	2716	9266	1790	5303	8653
8580	1063.00	5852	11269	23084	5294	8641	7018	21211	4731	11564	21360
3370	303	2231	3743	4371	1252	3589	2152	4838	1486	3790	4076
3260	267.00	3723	7181	7806	2309	6049	4228	8883	2891	7300	7489
3530	536.00	2702	5881	8775	1773	4741	2919	9278	2472	5917	7643
4740	1289.00	1897	3954	9733	1499	3199	1913	8595	1990	3807	6274
2540	410.00	2055	4724	9947	1466	3733	1882	9363	2537	4690	7885
2210	650.00	2052	1650	2954	1788	2480	1159	3847	2564	1540	2125
3210	601.00	1997	4429	24485	1198	3646	1942	7767	1740	4425	6603
4080	210.00	1792	3683	15682	991	3177	1871	5935	1408	3759	4632
855	16.00	4	1047	460	0	2201	84	0	33	1069	397
2880	482.00	1672	4297	5091	790	3504	2126	4339	1317	4185	2557
165	0.42	1	16	5	0	1	2	0	11	15	4
1570	245.00	1026	2166	31818	592	1818	1097	4839	1825	2437	3168
674	0.98	130	540	736	135	393	198	865	352	514	544
1270	292.00	1342	2347	3829	992	2220	943	4728	2099	2326	3218
1680	202.00	1675	2172	3036	1016	2498	1107	3556	1564	2184	2765
668	33.00	466	896	1460	192	922	377	1159	416	886	813

(Sheet 2 of 3)

Table 4 (Concluded)											
FLOW	QS	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
228	0.6	49	197	317	12	186	64	231	75	181	113
213	1.20	23	67	43	25	33	35	46	74	69	43
800	60.0	189	1327	22423	18	696	463	3549	816	4296	269119
1560	147.00	1635	3373	77141	750	2718	1090	9427	2756	2928	5259
7530	367.0	3149	9892	2621164	1391	5626	3155	27112	4774	7673	21786
2250	806.00	1655	4305	63926	1125	3229	1605	8825	2430	4323	7141
2190	429.0	1226	3236	16994	621	2643	1304	5090	1370	3258	3632
3000	279.0	3069	6051	19063	1935	5072	3054	9841	2992	5975	7605
603	26.00	166	253	230	106	260	156	239	199	253	212
289	1.77	44	229	132	36	239	72	79	85	230	112
											(Sheet 3 of 3)

Table 5
Observed Water and Sediment Discharge and Computed Bed Material Sediment Discharge using 10 Different Transport Functions for the Clark Corner Cutoff, AR. Sampling Station

FLOW	QS	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
589	200	0	3	7	0	0	1	0	0	3	1
9050	3537	42	38	45	526	42	78	1	76	37	49
4150	1293	85	254	148	436	87	196	36	108	243	145
1240	109	3	29	55	0	6	7	0	14	25	12
6350	961	3588	726	4605	1268	3672	1083	5200	3247	640	1705
449	9.0	0	1	2	0	0	1	0	0	1	0
221	14.0	0	0	0	0	0	1	0	0	0	0
26000	18836	24499	6907	250000	14361	25189	10221	57472	25527	6266	38460
30800	15990	36614	8347	260000	17317	37296	15785	67591	39400	8443	67561
1300	24	1	15	9	0	1	2	0	3	15	5
498	43	0	3	1	0	0	1	0	1	4	1
759	5	0	4	4	0	0	1	0	0	4	1
408	4.18	0	0	1	0	0	1	0	0	0	0
1090	30	0	11	18	0	0	1	0	4	11	4
6380	2407	867	317	1659	1861	890	541	2175	1312	297	756
3120	72	130	159	2342	170	142	147	2309	676	148	349
3960	101	334	266	3101	262	376	408	2076	600	394	1393
3130	110	32	120	98	129	35	74	106	64	116	52
2400	74	35	99	145	41	40	62	175	61	92	50
846	13	0	7	5	0	0	1	0	1	7	2
795	140	0	6	7	0	0	1	0	1	7	2
657	1.2	0	4	2	0	0	1	0	0	5	2
470	28	0	2	1	0	0	1	0	0	2	0
1110	27	0	13	8	0	1	2	0	4	14	3
2520	55	56	193	2219	77	84	96	1061	202	152	80
1940	64	11	65	453	103	13	22	165	79	58	69
2210	116	18	78	404	83	23	49	179	85	82	89
2480	27	30	96	225	85	36	63	97	81	91	100
1070	809	1	19	59	0	3	4	0	7	21	19
463	802	0	3	5	0	0	1	0	0	3	2
819	10	0	9	13	0	0	1	0	2	8	3
1140	30	1	21	49	0	3	3	0	9	19	10
1160	70	1	21	32	0	2	3	0	7	20	14
1240	112	3	40	311	0	8	5	0	27	36	46
23400	950	4460	3414	9355	17328	4825	5890	8225	6727	3216	6111
10300	724	538	398	679	949	551	586	610	572	369	507
2940	50	45	115	162	98	49	79	221	85	109	58
1580	18	1	12	11	0	1	2	0	4	12	5
1850	10	6	47	24	93	6	17	10	12	46	13
1460	17	3	29	10	0	3	8	0	7	29	6
1880	60	30	79	106	16	32	56	71	50	77	62
610	8.6	0	1	0	0	0	1	0	0	1	0
10400	3951	926	1339	5840	2448	1043	1688	2165	1578	1267	1384
21200	2804	3082	3721	6861	11230	3457	5287	5550	5023	3521	4501

(Continued)

Table 5 (Concluded)

FLOW	QS	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
2190	26	10	54	189	2497	14	26	198	52	49	23
26300	3544	7145	3952	9692	13893	7612	7143	7557	5666	3877	8158
8150	430	625	798	1761	900	678	1200	1120	786	882	943
1110	32	0	5	4	0	0	1	0	2	5	1
13300	2986	1997	1787	48964	5919	2120	3049	7319	5533	3797	2723
10300	2102	5189	2935	7733	7193	5660	3914	7170	3858	2916	6704
5610	42	1071	446	3342	1029	1111	555	4682	1822	405	991
10000	149	552	1519	735	259	876	981	301	341	1499	708
21300	749	961	1379	2731	2532	1005	1344	1391	1270	1344	1659
2290	12	6	62	27	536	6	23	17	11	62	18
9230	2213	738	960	1153	982	828	913	1180	775	884	702
21400	3494	7945	4120	740000	5322	8243	7655	37001	23120	4912	19355
15900	440	869	865	1423	2361	886	1424	842	1060	844	1212
15800	2399	2085	1641	8768	3596	2210	2253	4826	2756	1474	1863
12200	1069	1221	2140	4115	2816	1449	2496	1986	1544	2033	1875
3950	362	190	205	389	182	219	295	308	163	247	344
3260	269	77	134	173	144	86	125	121	115	128	139
7920	887	246	329	2372	489	261	417	1242	536	324	384
6130	1380	851	581	2859	1105	936	630	2171	947	500	729
8140	697	1389	729	2455	1521	1473	925	2095	1124	651	899
9190	1533	939	974	5361	1024	1046	1078	2318	1049	900	926
6470	740	820	404	1536	991	837	607	1587	954	364	533
16200	4435	10091	3539	38339	12733	10310	5930	18451	16670	2763	5569
11200	1705	976	1717	3193	1198	1156	1737	1792	1041	1522	1229
558	45	0	1	9	0	0	1	0	0	1	0
3600	24	0	0	0	0	0	1	0	0	0	0
718	5	0	4	41	0	0	1	0	0	4	2
2540	57	7	63	165	610	8	29	86	36	61	30
8770	2253	522	519	1581	451	543	556	1149	547	483	434
3230	108	48	117	188	53	56	90	54	78	112	119
836	3	0	1	1	0	0	1	0	1	0	0
1180	8	1	22	61	0	5	1	0	5	19	9
2990	105	37	156	245	134	44	98	170	83	151	89
2410	37	19	78	118	54	20	49	109	63	71	46
15300	3397	17212	5313	400000	10162	17760	5133	56755	23368	4078	29894
10100	891	8263	2898	210000	2760	8586	3662	27897	10240	4013	83048
7900	667	6562	2028	100000	962	6811	2708	20298	6684	3970	270000
6840	279	335	523	541	624	360	610	300	412	520	483
2660	67	10	59	89	394	12	25	69	28	56	22
397	7.8	0	1	1	0	0	1	0	0	0	0

The output in Tables 3-5 were used as a basis for further research as discussed in Chapter 4.

4 Analysis and Results

Sediment Transport

In order to evaluate the field data, a method had to be devised to measure the value of the data, both as a complete set and incrementally. The sediment transport values calculated with the SAM software and depicted in Tables 3-5 were generated to provide a means for assisting in answering the question, "How much sediment data are necessary?" While it is customary to use the field data to select a sediment transport function (Julien, 1995). It is also possible that the transport functions could be used to evaluate the incremental and total value of the data sets.

In order to accomplish this, it was first necessary to determine which transport functions best reproduced the measured field data. Water discharge values were plotted versus values from the 10 selected transport functions and the observed data. For ease of reading, these were plotted five to a graph. Figure 6 depicts a plot of water discharge vs. sediment discharge for the observed sediment discharge and five predictive equations for the Fisk, MO, Station. This shows graphically how well the equations reproduced the observed data. Figure 7 depicts similar relationships for the other five predictive

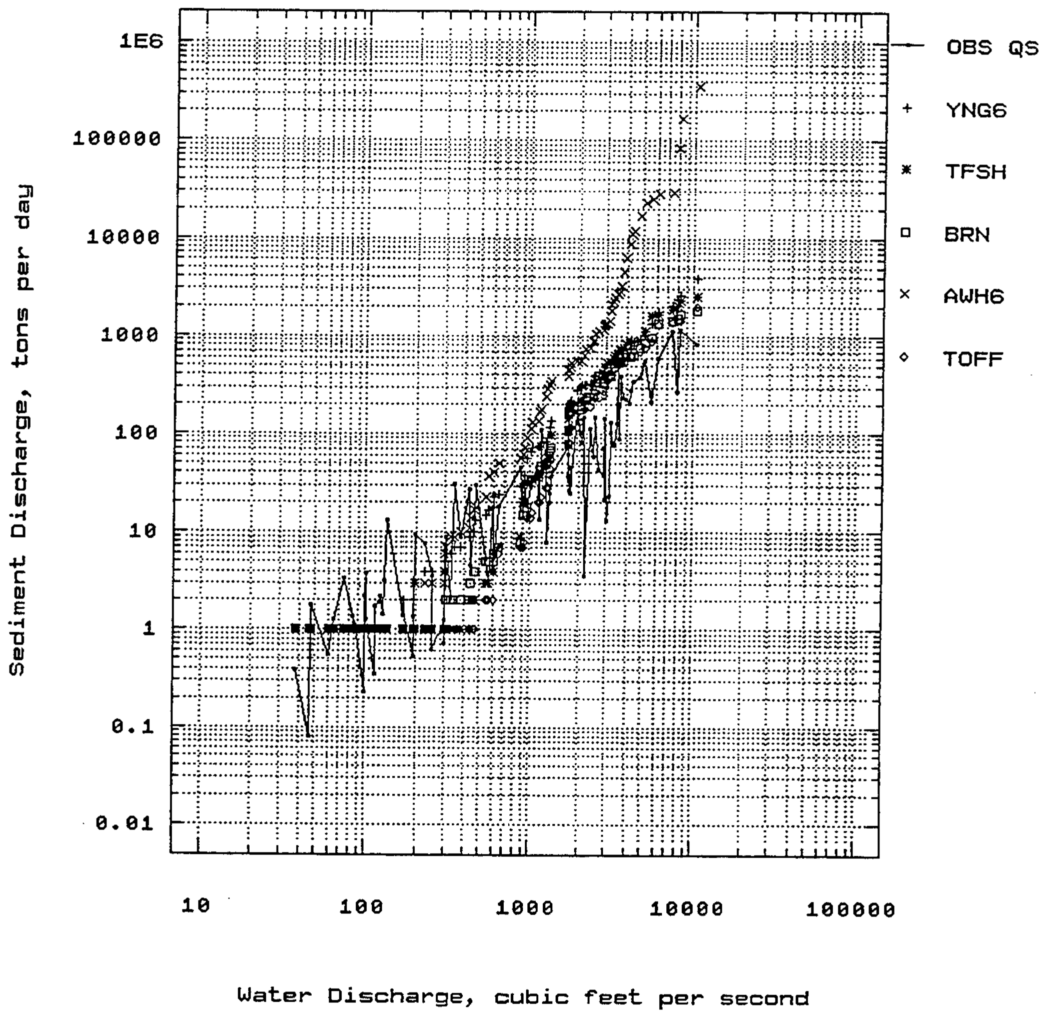

Figure 6. Water vs. sediment discharge, five transport functions, Fisk, MO

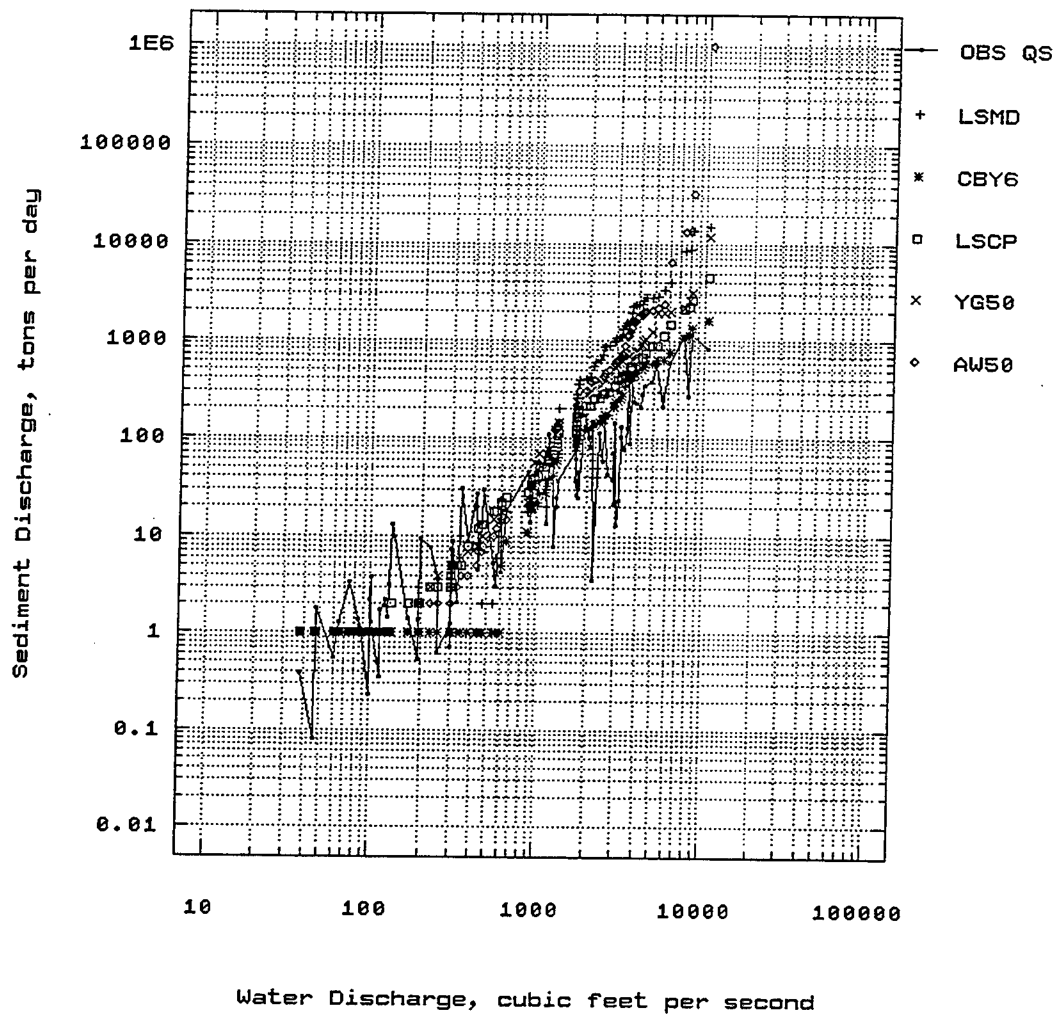

Figure 7. Water vs. sediment discharge, other transport functions, Fisk, MO

equations. Similarly, Figures 8 and 9 depict the water discharge vs. sediment discharge relations for five predictors for the Wilhelmina Cutoff station. Figures 10 and 11 show the predictors for the Clark Corner station. These visual plots, while informative, do not present results in a quantitative manner which establishes a firm basis for evaluation of which of the functions best fit the observed sediment data. Other quantitative methods were applied to this end and the results are discussed below.

Regression Analysis

While visual observation of the water vs. sediment discharge plots showed general comparisons of the measured vs. computed sediment transport, it was insufficient to rank the performance of the various sediment transport prediction functions. To this end, a simple regression analysis was made for each transport function as compared to the measured bed material load. The correlation coefficients, R, were computed for each set of measured vs. computed data. Using these, the coefficient of determination, R^2, were computed in each case. The coefficient of determination is the value of the correlation coefficient, squared. This value, R^2, is a ratio of the explained variation in the dependent variable, in this case the computed sediment discharge, to the total variation of the dependent variable. The transport functions were then ranked from one to ten, with "one" indicating the highest coefficient of determination and "ten" the worst. These results are shown in Table 6 for Fisk, MO.

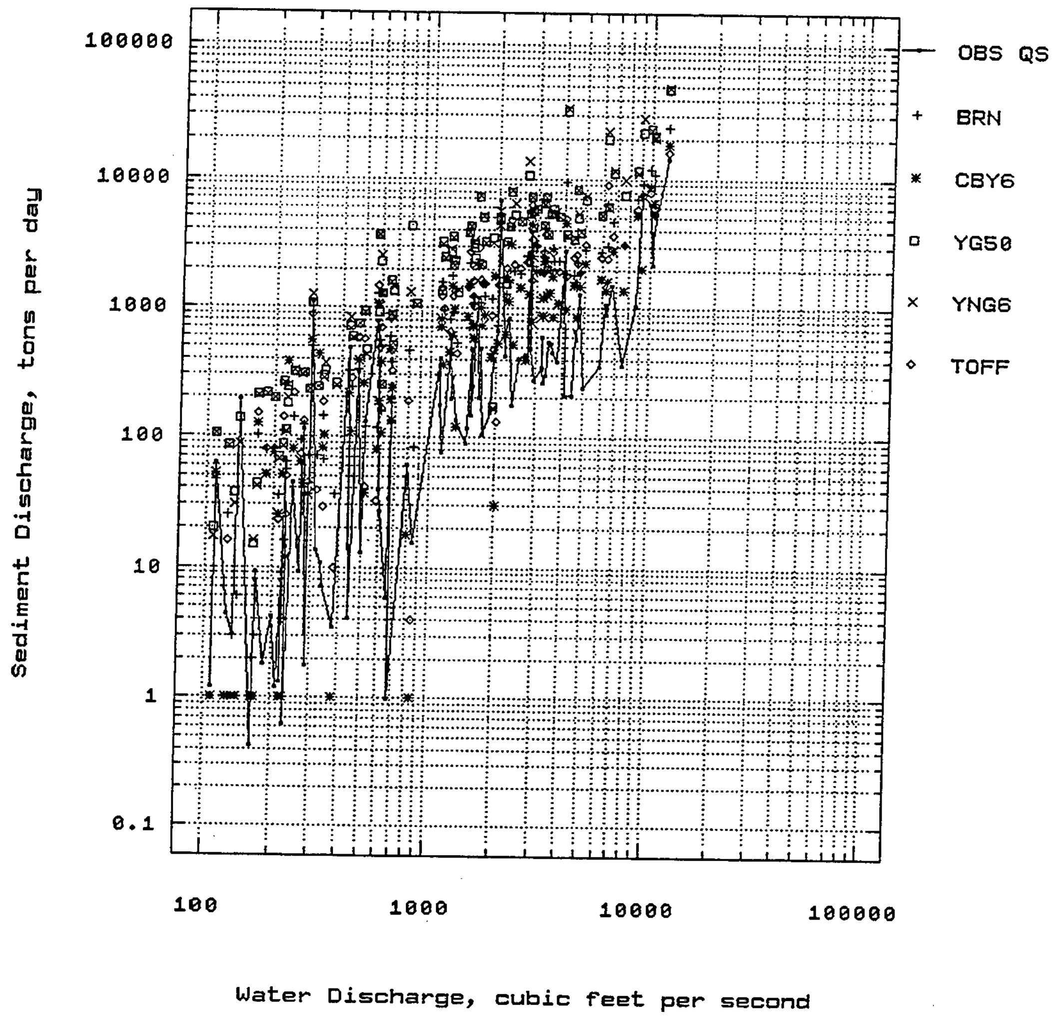

Figure 8. Water vs. sediment discharge, five transport functions, Wilhelmina, MO

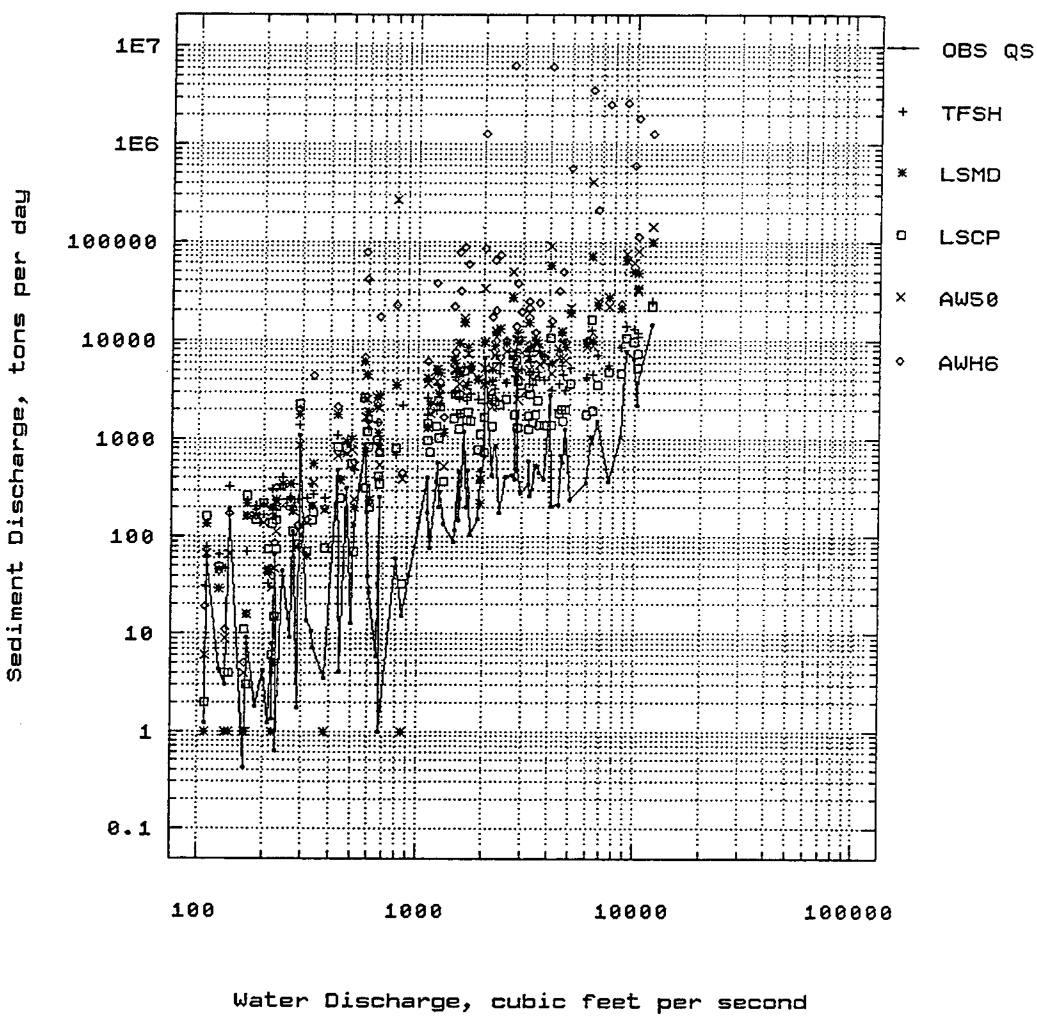

Figure 9. Water vs. sediment discharge, other transport functions, Wilhelmina, MO

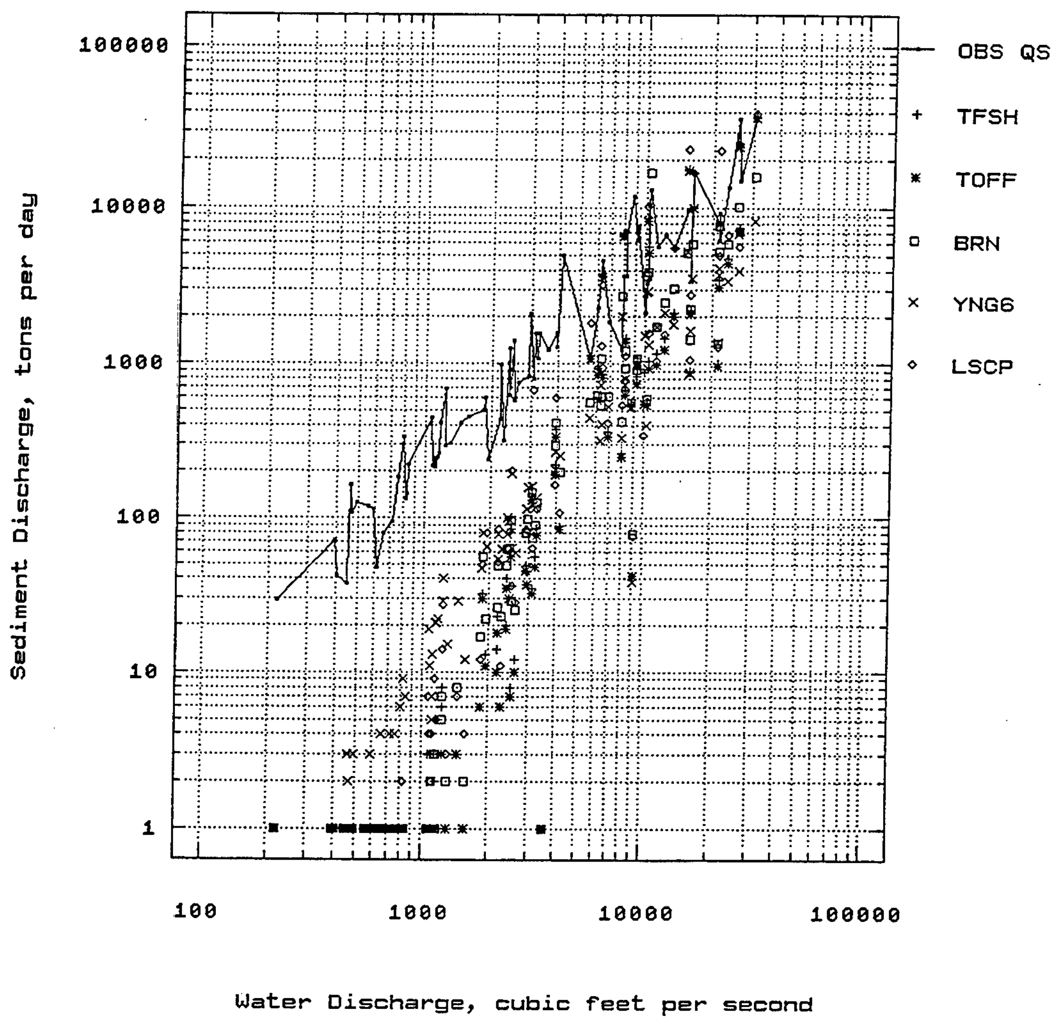

Figure 10. Water vs. sediment discharge, five transport functions, Clark Corner, AR

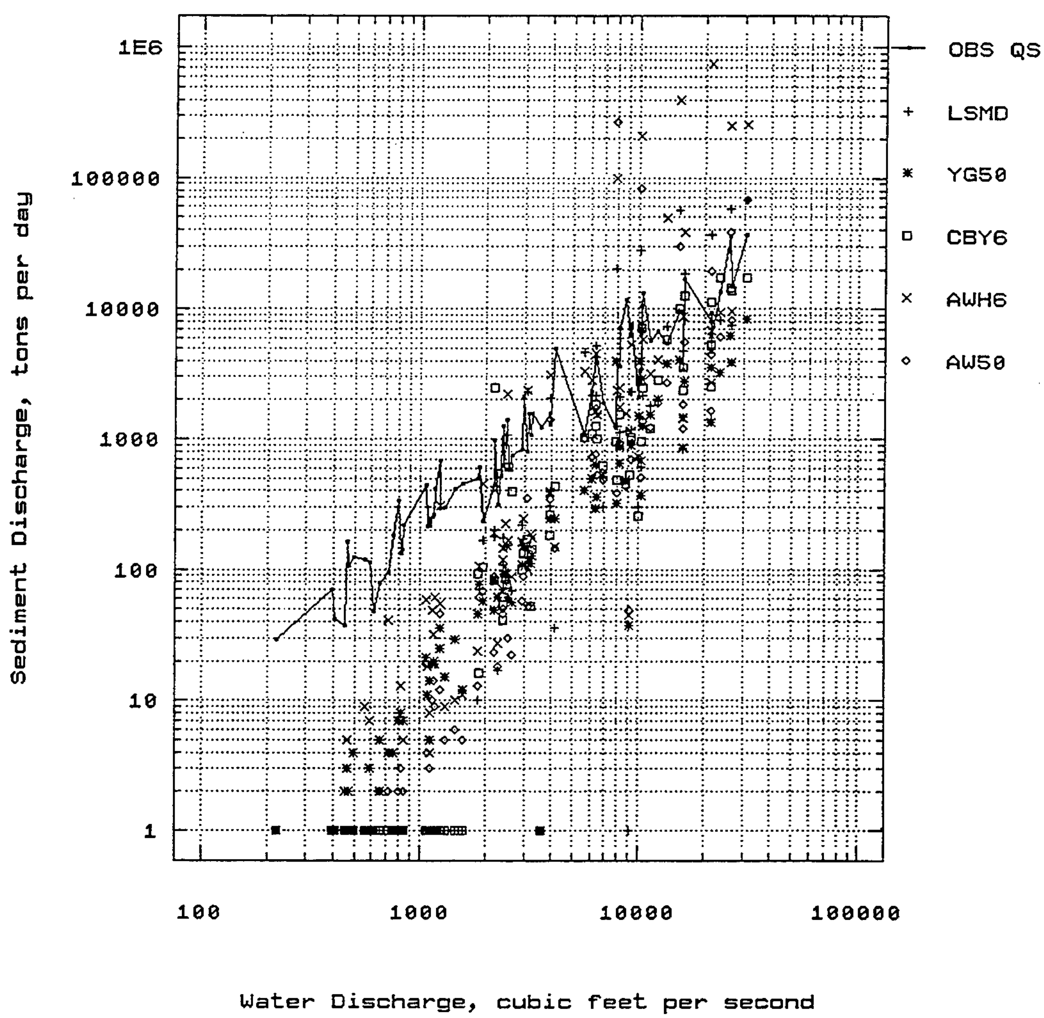

Figure 11. Water vs. sediment discharge, other transport functions, Clark Corner, AR

Table 6
Coefficients of Determination for Each Transport Function Regressed Against the Measured Values Fisk, MO

Measured Sediment Discharge Regressed Against	Coefficient of Determination, R^2	Rank
Toffaleti	32.16	5
Yang-HEC6	49.92	1
Ackers-White-HEC6	35.56	4
Colby-HEC6	25.27	7
Toffaleti-Schoklitsch	39.75	2
Brownlie	36.00	3
Laursen-Madden	27.49	6
Laursen-Copeland	15.44	8
Yang, d_{50}	6.86	9
Ackers-White, d_{50}	0.09	10

It can be seen that even the top rated transport function, Yang-HEC6, has less than one half of its variation explained. This indicates that it is very poorly correlated with the observed data. The Yang-HEC6 function was, however, clearly better than any of the others. That it performed best is not surprising since it was developed for sand-bed streams. The WES modifications to allow sediment transport calculations by size class greatly improve the function in this case. The unmodified single grain size version finished rated ninth. The Ackers-White single grain size function was the worst performer, with almost no explained variation. It therefore has almost no correlation to the observed data. This equation has previously been reported to be a poor predictor for broadly graded samples (Prasuhn et al., 1987). In addition, it was developed for a maximum grain size of 2.5 mm, which was exceeded by a number of the samples at Fisk.

The Yang single grain size function was also a very poor performer. Careful study of the data (see Appendix A) revealed that a wide variability existed in the bed material samples. The maximum size ranged from 16 mm to .0625 mm. The average d_{50} size was 0.3549 mm. However, there were five samples where the maximum size present in the bed was 16 mm, three samples where the maximum size was 8mm and three samples where the maximum size was 4 mm. This wide variability of bed material size limits the ability of any one sediment transport function to be a good predictor, especially the single grain size functions. In fact it is quite remarkable that the Brownlie single grain size function did as well as it did (third overall). The average d_{50} for all the observations is classified as a fine sand. However, the maximum d_{50} is 6.0 mm. This is in the range of fine gravel. Therefore, the wide variability in bed material size limits the ability of any of the transport functions to accurately reproduce the observed data. With this limitation in mind, the results were kept and the analysis continued. If a procedure could be developed which covered this eventuality as well as more conventional data, then it would be robust indeed. More conventional results were obtained for Wilhelmina and Clark Corner Cutoffs, as shown in Tables 7 and 8.

These sediment data were far less variable than those at Fisk. The average d_{50} was 0.1775 mm. The maximum grain size was 2.0 mm for two samples. The remainder of the samples had a maximum grain size of 1.00 mm. This lack of variability is reflected in the much higher coefficient of determination values for Wilhelmina as compared to those for Fisk. It should be noted that the Ackers-White function continued to suffer from its

Table 7
Coefficients of Determination for Each Transport Function Regressed Against the Measured Values Wilhelmina Cutoff, MO

Measured Sediment Discharge Regressed Against	Coefficient of Determination, R^2	Rank
Toffaleti	62.97	5
Yang-HEC6	65.73	4
Ackers-White-HEC6	8.24	10
Colby-HEC6	68.53	2
Toffaleti-Schoklitsch	62.91	6
Brownlie	72.82	1
Laursen-Madden	61.62	7
Laursen-Copeland	60.76	8
Yang, d_{50}	65.75	3
Ackers-White, d_{50}	10.85	9

Table 8
Coefficients of Determination for Each Transport Function Regressed Against the Measured Values Clark Corner Cutoff, AR

Measured Sediment Discharge Regressed Against	Coefficient of Determination, R^2	Rank
Toffaleti	78.44	2
Yang-HEC6	68.97	4
Ackers-White-HEC6	22.79	9
Colby-HEC6	52.33	8
Toffaleti-Schoklitsch	78.46	1
Brownlie	71.69	3
Laursen-Madden	65.87	6
Laursen-Copeland	68.57	5
Yang, d_{50}	61.98	7
Ackers-White, d_{50}	5.47	10

sensitivity to broadly graded bed material in both its single and multiple grain size versions. The Brownlie function finished first at Wilhelmina. This, coupled with its third place finish at Fisk indicate that it is a versatile function and indicate the strength of the regression-based approach used to develop this function (Brownlie, 1981).

The highest coefficients of determination of the three stations analyzed were computed for Clark Corner Cutoff. The variation in bed material was limited at this station, and this undoubtedly contributed to the overall better performance of the transport functions. In these data, one sample had a maximum grain size of 8.0 mm and seven samples had a maximum size of 2.0 mm. The rest were fairly uniform. Even the 2.0 mm value is in the medium to coarse sand range. The average d_{50} for this station was 0.2748 mm. Therefore, the selected transport functions should, and did, by and large perform quite well at this station. The hybrid Toffaleti-Schoklitsch function was the top rated function. It should be noted that it is only very marginally better than the Toffaleti transport function. This indicated that the Toffaleti function was used for virtually all of the computations, as would be expected. Brownlie also did quite well again and finished third. The two Ackers-White functions, as was the case in general for all the stations, were very poor performers. This is all the more puzzling since, based on the conditions for which it is recommended, it should have been a good predictor. The likely explanation lies in the fact that the Ackers-White function is based on a mobility number and a dimensionless grain diameter. The mobility number is a stream power derivative and should function as well as the Yang stream power based function. The dimensionless grain diameter, however, seems more problematic. In comparing the function to actual field data, Ackers and White had to abandon the d_{50} grain size in favor of the d_{35} grain size in order to best match the selected field data. The SAM program uses the d_{35} grain size. However, for the St. Francis data, this value may be quite variable. As this was the only function that used the d_{35} value and it was a poor predictor in general, this possibility was not investigated further.

The above analyses were performed using the full eleven years of record at each station. It was recognized that to meet the research objective, the minimum number of years of record required to select the best transport function must be determined. To this end, the regression analyses were repeated for each station. However, the analysis at each station was broken into eleven segments. The first segment contained only the first year of record. Segment number two contained the first two years of record and so on until segment number eleven contained the full record. This was repeated for each of the three stations. The sediment transport equations were ranked for each segment as described above. The notion here is that if, for instance, the beginning order of rank of the transport functions does not change as additional data are added, then the additional data did not aid in making a better selection of a transport function that represents the data. The other extreme possibility was that the order would continuously shift, indicating no pattern. It was also necessary to select the best transport function for use in application of the entropy principles described below.

The coefficients of determination for the Fisk, MO, station for each segment of data are tabulated in Table 9. (Note. Abbreviations used in Tables 9-14 are the same as those previously defined for Tables 3-5.) They are plotted in Figure 12 (best five predictors) and Figure 13 (other five predictors) versus the number of years of data. Table 10 shows the rank order of each transport function as they varied with an increasing number of data points in the data set. The top four functions are high-lighted in bold for each segment. These data are plotted in Figure 14 (best five predictors) and Figure 15 (other five predictors).

Table 9
Coefficient of Determination Between Measured and Observed Sediment Transport with Increasing Number of Years of Data, Fisk, MO

YEAR	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
1	48.64	51.28	45.70	63.79	50.53	55.90	49.38	52.61	62.36	45.42
2	45.08	57.23	36.88	34.22	51.74	44.18	45.53	52.15	44.23	2.22
3	47.08	58.22	37.31	35.42	53.76	47.00	46.10	52.53	46.64	3.89
4	46.60	57.80	37.56	35.82	52.67	44.22	45.98	52.31	3.16	0.24
5	36.76	56.76	37.33	26.05	45.95	42.09	47.00	51.07	3.88	0.16
6	35.67	49.73	37.02	25.98	42.43	35.54	41.02	43.93	4.28	0.15
7	34.18	49.40	36.85	25.00	41.26	35.37	41.42	43.88	4.60	0.13
8	33.93	50.63	38.62	25.99	41.31	35.16	42.87	33.47	6.07	0.15
9	33.36	49.38	35.37	25.91	40.30	35.65	40.03	31.41	6.09	0.16
10	34.26	50.14	35.58	26.69	41.21	36.58	40.70	32.12	6.58	0.12
11	32.16	49.92	35.56	25.27	39.75	36.00	27.49	15.44	6.86	0.09

Table 10
Relative Rank of Sediment Transport Equations with Increasing Number of Years of Data, Fisk, MO

NO. YEARS	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
1	8	5	9	**1**	6	**2**	7	**3**	**4**	10
2	5	**1**	8	9	**3**	7	**4**	**2**	6	10
3	**4**	**1**	8	9	**2**	5	7	**3**	6	10
4	**4**	**1**	7	8	**2**	6	5	**3**	9	10
5	7	**1**	6	8	**4**	5	**3**	**2**	9	10
6	6	**1**	5	8	**3**	7	**4**	**2**	9	10
7	7	**1**	5	8	**4**	6	**3**	**2**	9	10
8	6	**1**	**4**	8	**3**	5	**2**	7	9	10
9	6	**1**	5	8	**2**	**4**	**3**	7	9	10
10	6	**1**	5	8	**2**	**4**	**3**	7	9	10
11	5	**1**	**4**	7	**2**	**3**	6	8	9	10

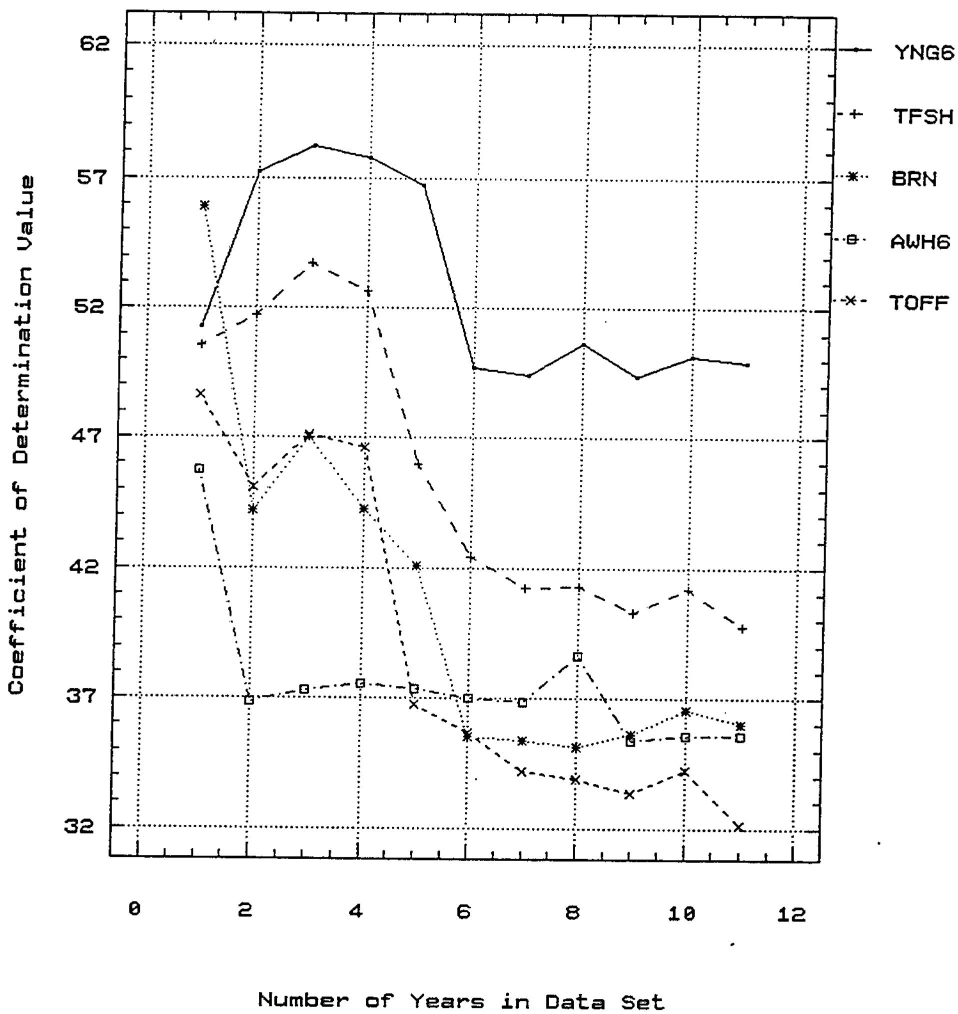

Figure 12. Variability of the coefficient of determination values as more data are added, best five transport functions, Fisk, MO

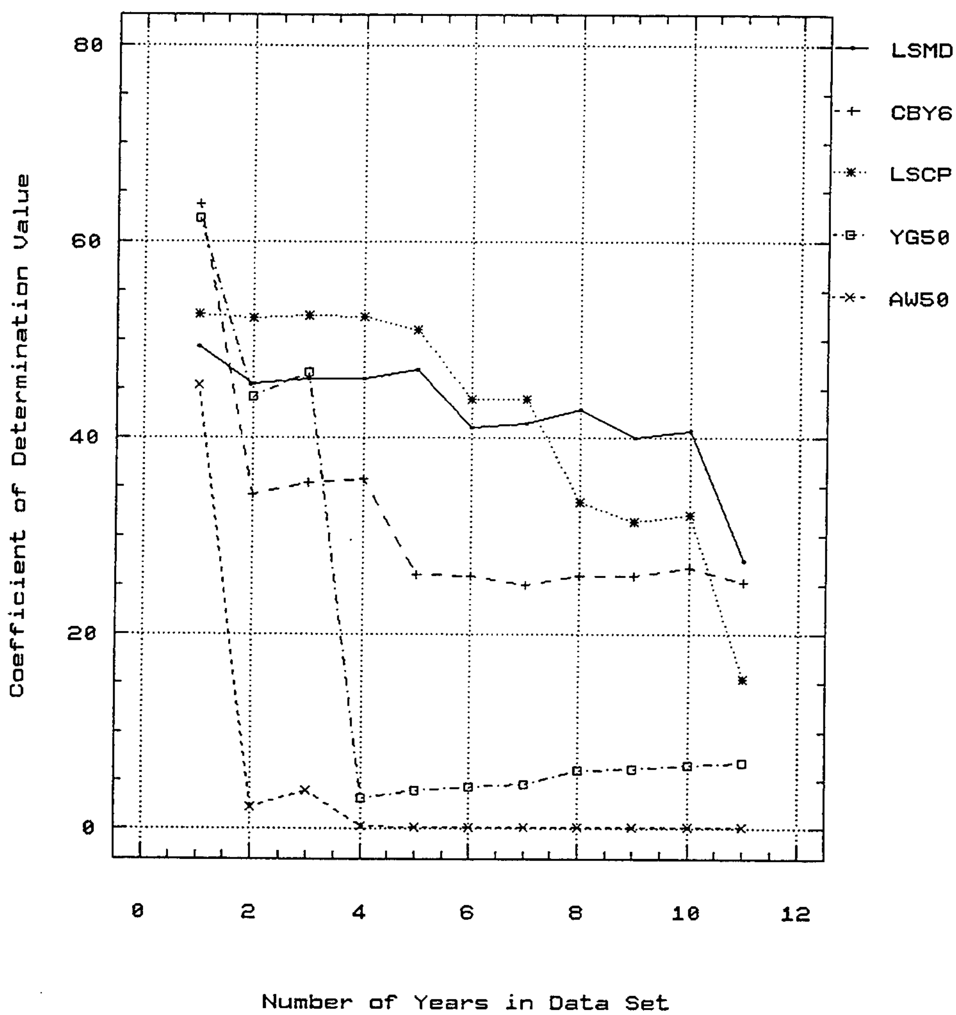

Figure 13. Variability of the coefficient of determination values as more data are added, other transport functions, Fisk, MO

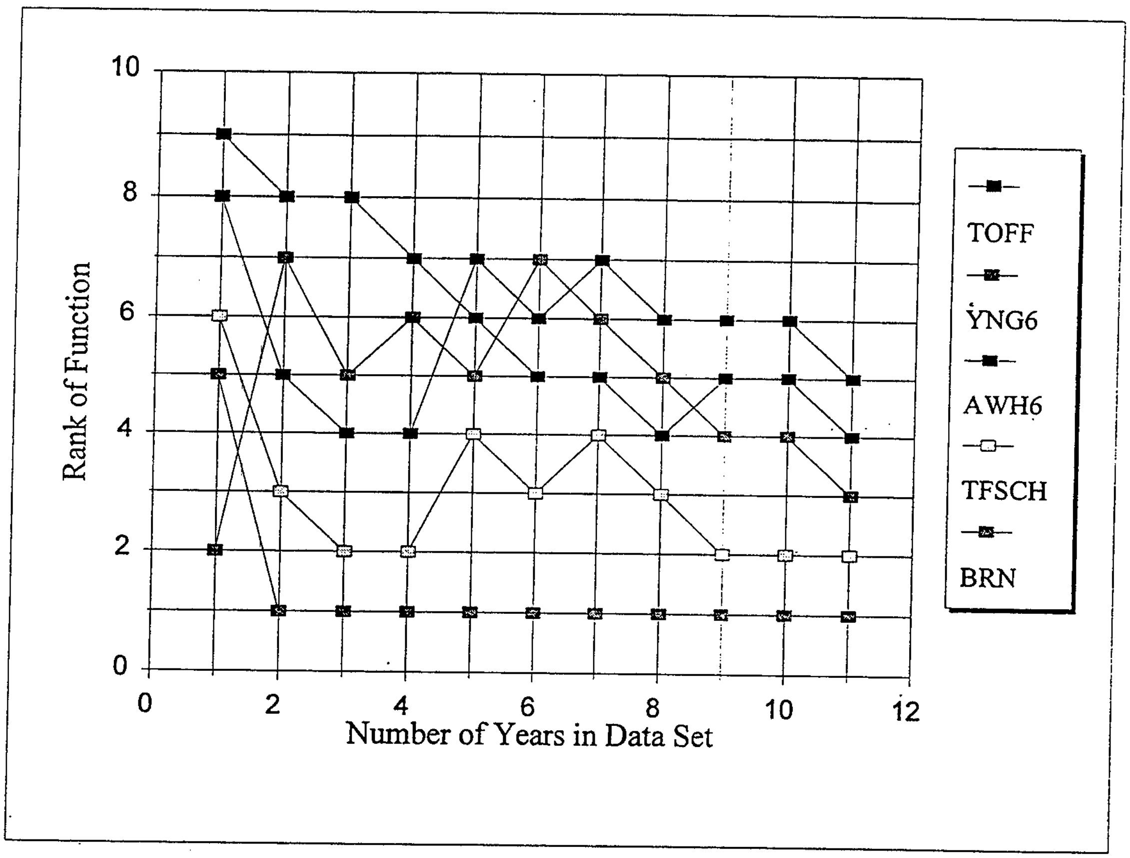

Figure 14. Number of years of data vs. rank of the best five transport functions, Fisk, MO

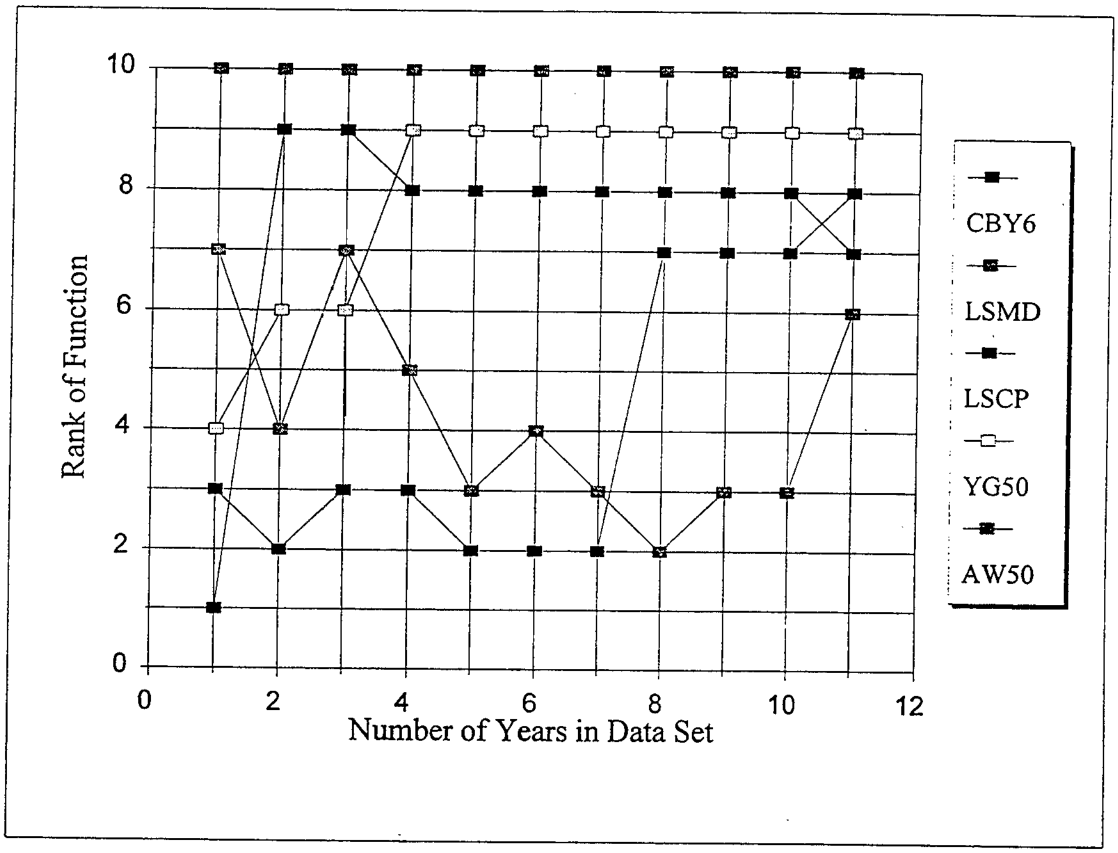

Figure 15. Number of years of data vs. rank of the other five transport functions, Fisk, MO

It can be seen that selection of a transport function based on the top ranked function after one year of data (Colby-HEC6) would result in a very poor long-term selection. This is proven as it drops to ninth in year two and never climbs higher than seven during the period of record. Selection of the top rated function using two years of data would result in the same choice as that based on eleven years of data. Note that after seven years, there is also less shifting of rank among the top four ranked functions.

The coefficients of determination for the Wilhelmina Cutoff Station for each segment of data are tabulated in Table 11. They are plotted in Figure 16 (best five predictors) and Figure 17 (other five predictors). Table 12 shows the rank order of each transport function as they varied with an increasing number of data points in the data set, again with the top four highlighted for each segment These data are plotted in Figure 18 (best five predictors) and Figure 19 (other five predictors).

The choice of the top rated function based on one year of data, as was the case at Fisk, would not result in the best long-term selection. Selection of the top rated function using two years of data would result in the same choice as that based on eleven years of data, which was the same conclusion drawn from the Fisk data. Also as at Fisk, note that after seven years there is much less shifting of rank among the top four ranked functions.

The coefficients of determination for the Clark Corner Cutoff Station for each segment of data are tabulated in Table 13. They are plotted in Figure 20 (best five predictors) and Figure 21 (other five predictors). Table 14 shows the rank order of each transport function as they varied with an increasing number of data points in the data set.

Table 11
Coefficient of Determination Between Measured and Observed Sediment Transport with Increasing Number of Years of Data, Wilhelmina Cutoff, MO

YEAR	TOFF	YGH6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
1	21.56	14.64	7.24	10.27	20.12	15.46	14.99	13.27	13.45	8.85
2	34.09	31.43	4.29	27.06	38.66	42.89	25.67	20.90	27.80	1.42
3	35.33	35.63	7.11	25.35	40.78	44.75	29.97	24.75	31.90	2.89
4	35.65	37.37	8.95	25.33	40.70	44.71	32.31	27.05	33.48	3.93
5	36.09	38.01	9.55	24.82	40.10	44.17	33.31	28.45	34.21	4.45
6	45.85	45.99	8.08	40.73	47.95	51.85	42.28	36.87	43.93	5.96
7	44.41	45.74	8.22	39.32	46.77	51.17	41.82	36.56	43.63	6.11
8	63.88	66.01	8.26	68.52	63.89	73.13	62.33	61.38	65.93	15.34
9	63.54	65.86	8.44	63.35	63.54	72.89	62.34	61.31	65.74	15.51
10	63.79	62.26	8.80	68.67	63.72	73.20	62.81	61.65	66.13	15.97
11	62.97	65.73	8.24	68.53	62.91	72.82	61.62	60.76	65.75	10.85

Table 12
Relative Rank of Sediment Transport Equations with Increasing Number of Years of Data, Wilhelmina Cutoff, MO

YEARS	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
1	1	5	10	8	2	3	4	7	6	9
2	3	4	9	6	2	1	7	8	5	10
3	4	3	9	7	2	1	6	8	5	10
4	4	3	9	8	2	1	6	7	5	10
5	4	3	9	8	2	1	6	7	5	10
6	4	3	9	7	2	1	6	8	5	10
7	4	3	9	7	2	1	6	8	5	10
8	6	3	10	2	5	1	7	8	4	9
9	4	2	10	6	5	1	7	8	3	9
10	4	7	10	2	5	1	6	8	3	9
11	5	4	10	2	6	1	7	8	3	9

Table 13
Coefficient of Determination Between Measured and Observed Sediment Transport with Increasing Number of Years of Data, Clark Corner Cutoff, AR

YEAR	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
1	0.62	0.23	0.74	11.32	0.63	0.04	0.79	0.48	0.17	0.41
2	88.29	93.89	96.41	95.58	88.55	87.24	94.31	87.53	91.47	83.89
3	88.78	93.83	95.82	94.98	89.02	88.25	94.07	88.09	91.50	84.41
4	89.10	93.95	95.82	95.13	89.33	88.59	94.21	88.43	91.71	84.79
5	88.80	86.90	95.81	60.76	88.94	82.00	93.91	87.46	85.27	84.75
6	87.23	80.61	92.41	52.79	87.43	76.92	91.95	86.33	79.16	83.15
7	86.68	77.73	92.09	52.56	86.82	76.33	91.60	86.32	73.99	82.72
8	86.16	74.88	25.23	52.60	86.30	73.00	84.71	77.25	69.98	81.17
9	85.90	74.80	25.04	52.10	86.07	73.19	84.69	76.06	70.34	80.27
10	85.61	74.82	25.21	52.31	85.78	73.08	84.43	75.91	70.42	79.95
11	78.44	68.97	22.79	52.33	78.46	71.69	65.87	68.57	61.98	5.47

Table 14
Relative Rank of Sediment Transport Equations with Increasing Number of Years of Data, Clark Corner Cutoff, AR

YEAR	TOFF	YNG6	AWH6	CBY6	TFSH	BRN	LSMD	LSCP	YG50	AW50
1	5	8	3	1	4	10	2	6	9	7
2	6	4	1	2	7	9	3	8	5	10
3	7	4	1	2	6	8	3	9	5	10
4	8	4	1	2	7	6	3	9	5	10
5	4	6	1	10	3	9	2	5	7	8
6	4	7	1	10	3	8	2	5	9	6
7	4	7	1	10	3	8	2	5	9	6
8	2	6	10	9	1	7	3	5	8	4
9	2	6	10	9	1	7	3	5	8	4
10	2	6	10	9	1	7	3	5	8	4
11	2	4	9	8	1	3	6	5	7	10

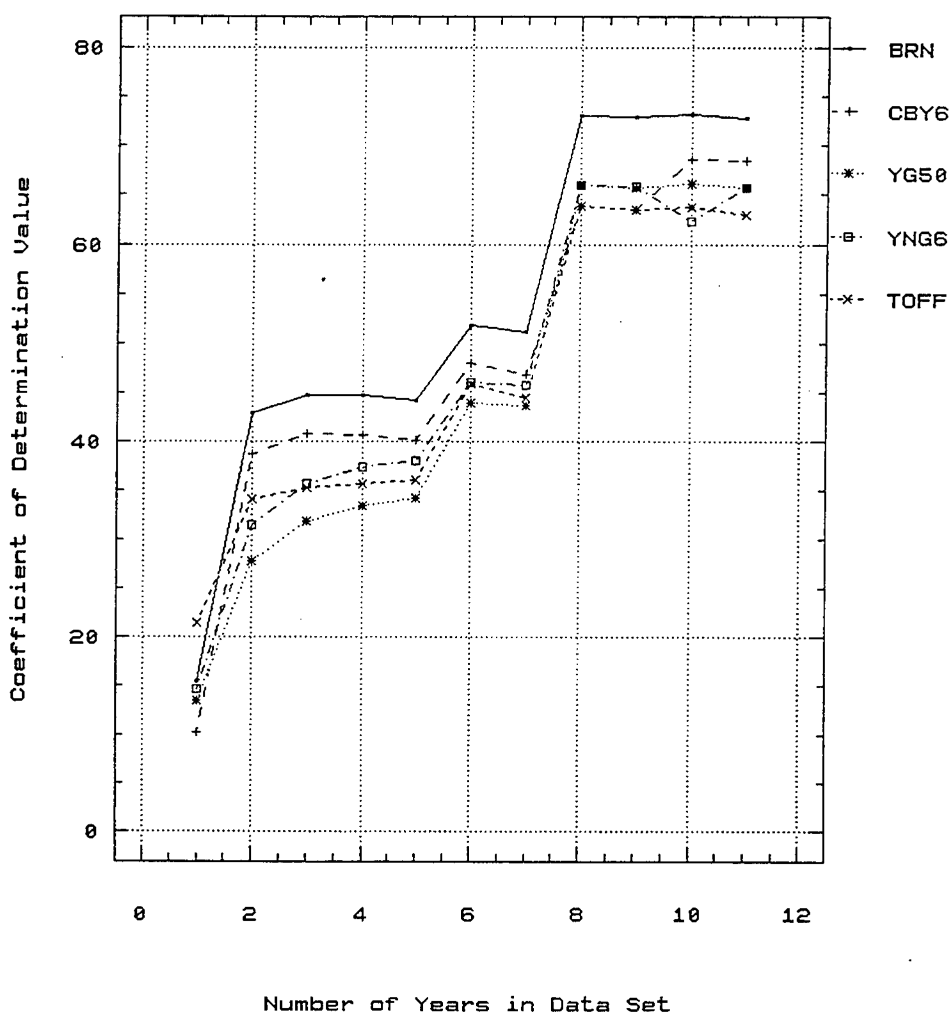

Figure 16. Variability of the coefficient of determination values as more data are added, best five transport functions, Wilhelmina, MO

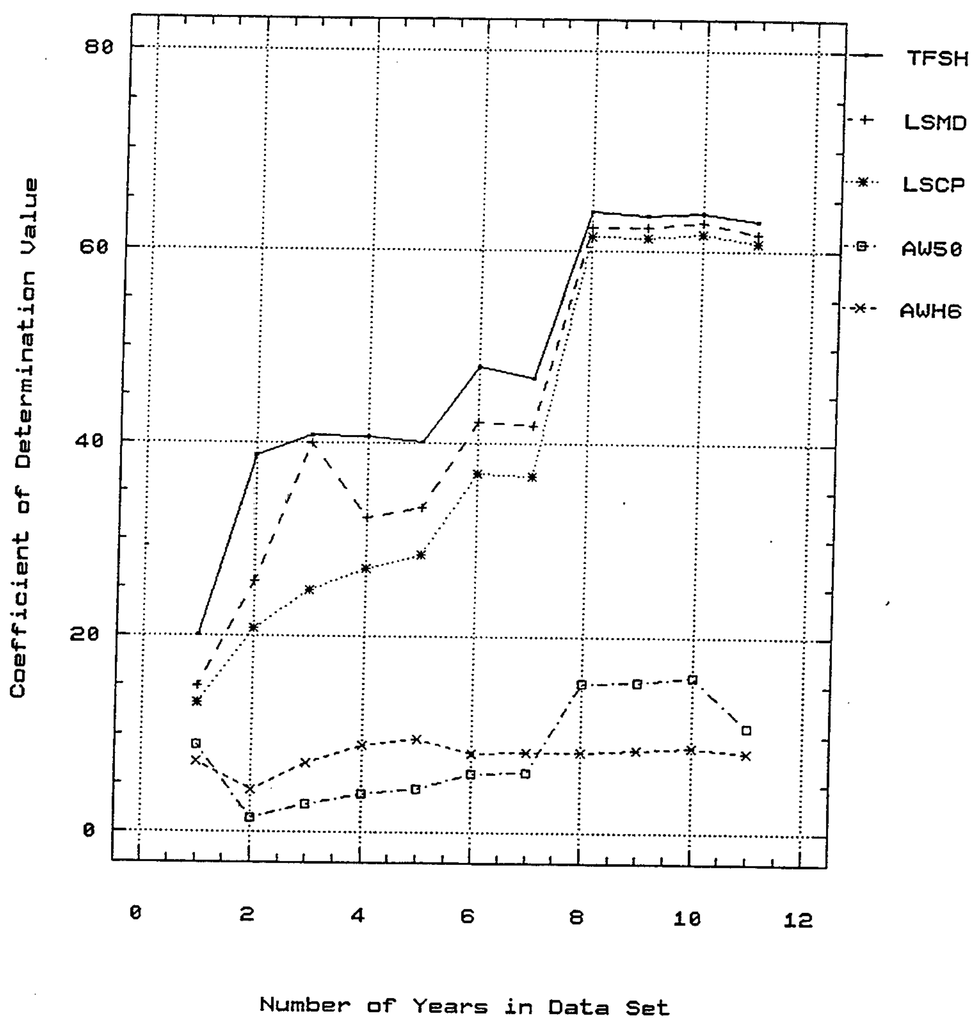

Figure 17. Variability of the coefficient of determination values as more data are added, other transport functions, Wilhelmina, MO

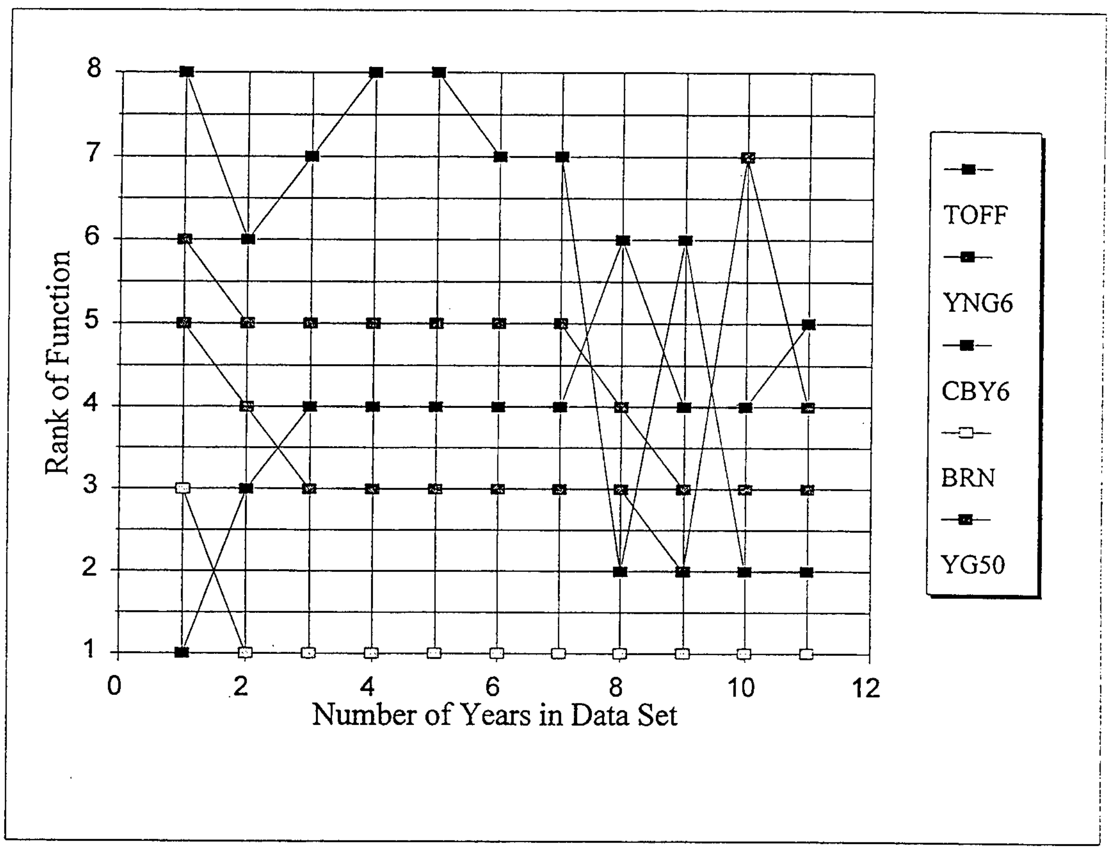

Figure 18. Number of years of data vs. rank of the best five transport functions, Wilhelmina, MO

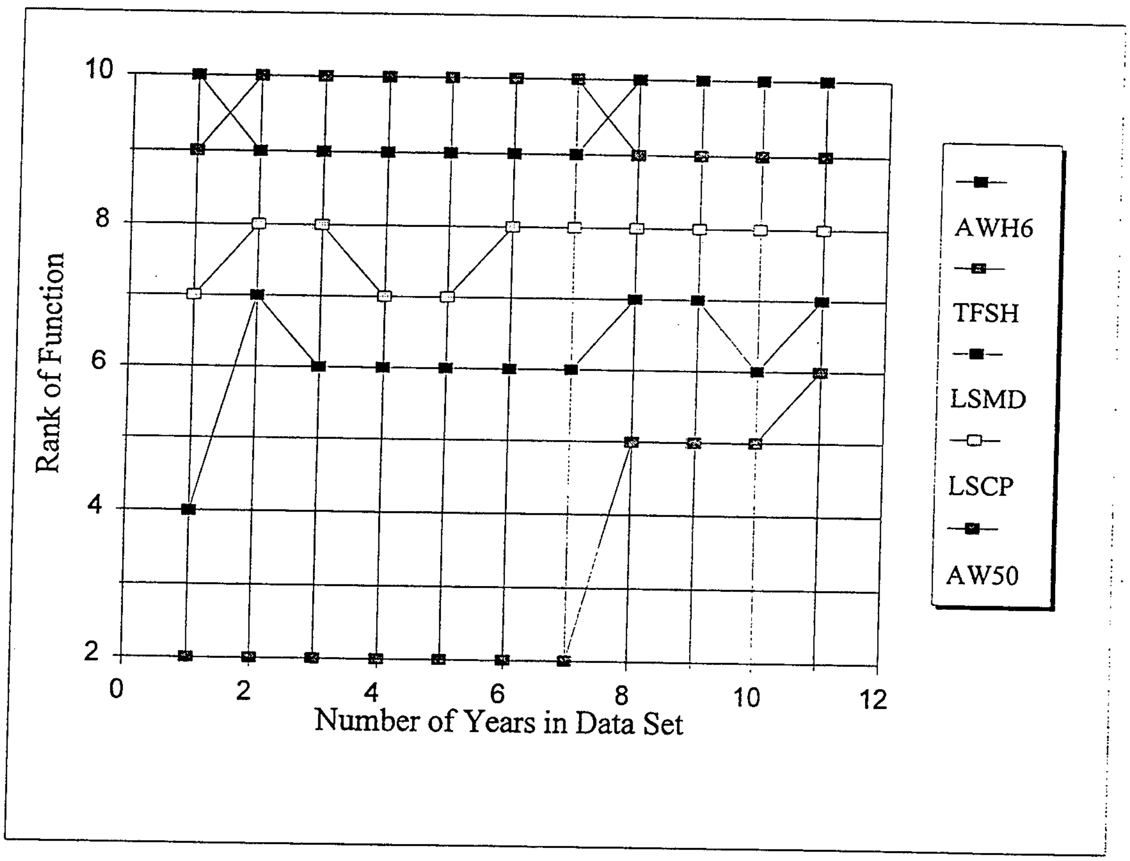

Figure 19. Number of years of data vs. rank of the other transport functions, Wilhelmina, MO

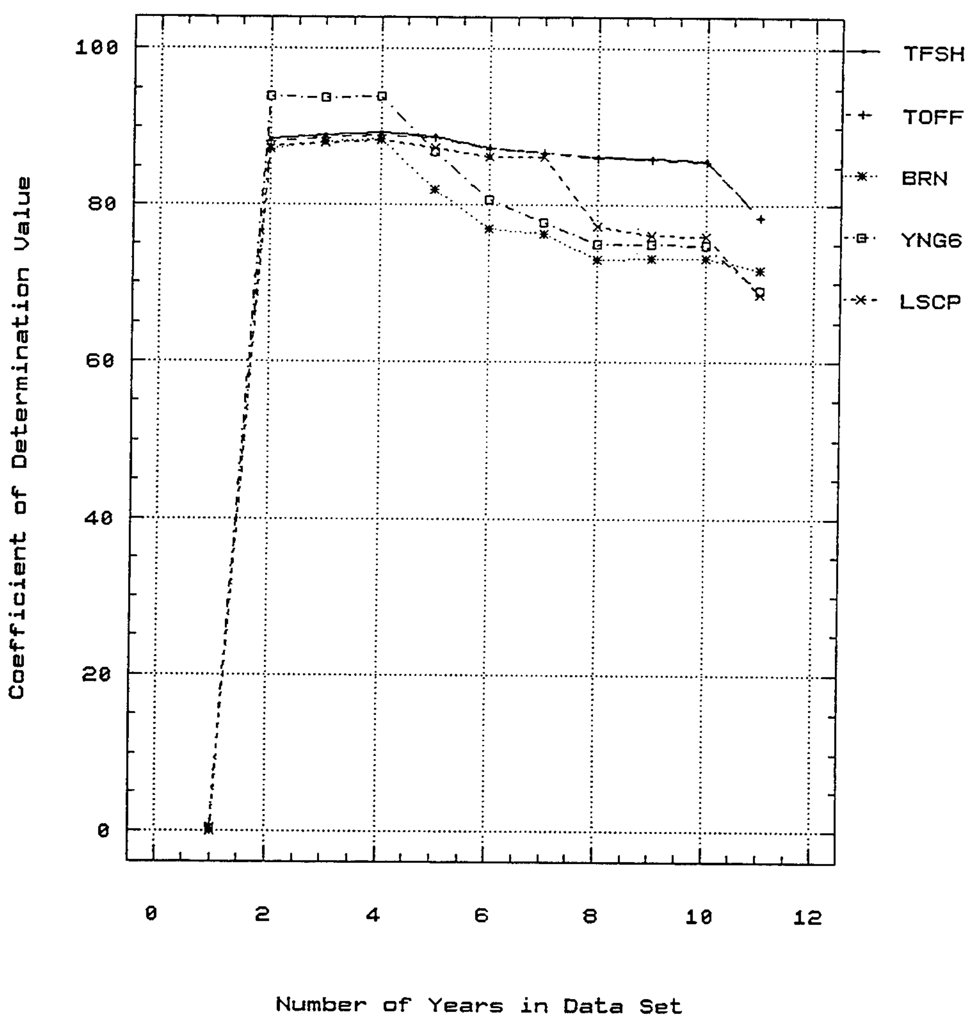

Figure 20. Variability of the coefficient of determination values as more data are added, best five transport functions, Clark Corner, AR

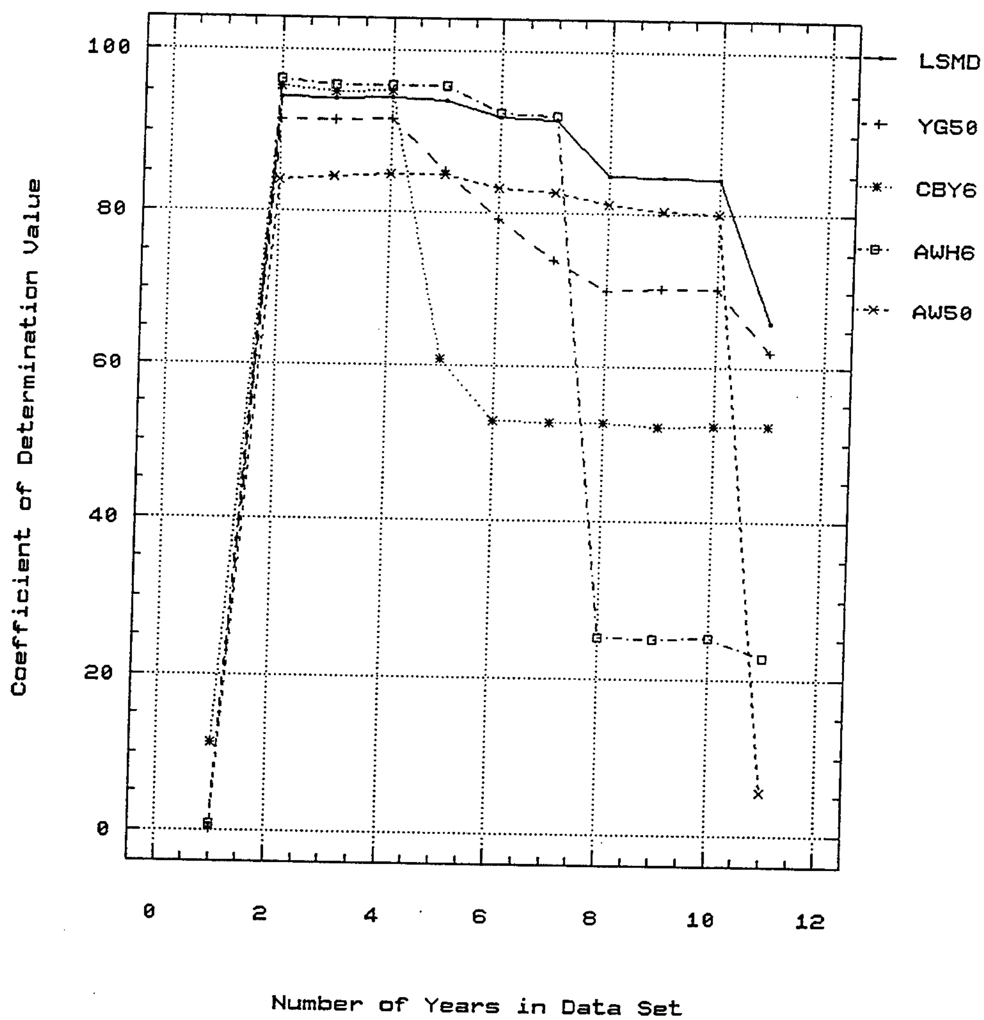

Figure 21. Variability of the coefficient of determination values as more data are added, other transport functions, Clark Corner, AR

The top four are again highlighted in bold for each segment. These data are plotted in Figure 22 (best five predictors) and Figure 23 (other five predictors).

As was true at Fisk and Wilhelmina, selection of the top rated function based on one year of data would result in a poor long term selection. Selection of the top rated function using two years of data would also result in a poor long-term selection. This result is quite different from the conclusion drawn from the previous two stations. That is, that the selection based on two years of data results in the same choice as that based on eleven years of data. In fact, it is only after eight years that the selection of the top rated function results in the best long term selection. It is, however, true that the variability of the top four rated functions is minimal after eight years, same as for the previous two stations.

For this analysis it is assumed that the top ranked transport function based on the full eleven years of record is the long term best choice with which to make predictions of sediment transport at a given station. This is logical since such a function has endured the rigors of variability inherent in sedimentation data. Indeed, the accepted and usual method of selecting a transport function is to compare several of them to observed data by some method and select the one that best reproduces the observed data (Vanoni, 1975, USACE, 1989, Julien, 1995). However, as can be seen from the preceding analysis, a different selection would be made at the same station depending on how much data were available for inclusion in the selection process. At Fisk and Wilhelmina two years of data are sufficient to select the best transport function based on the full eleven years of record. Eight years of data are necessary at Clark Corner to select the best function. Variability

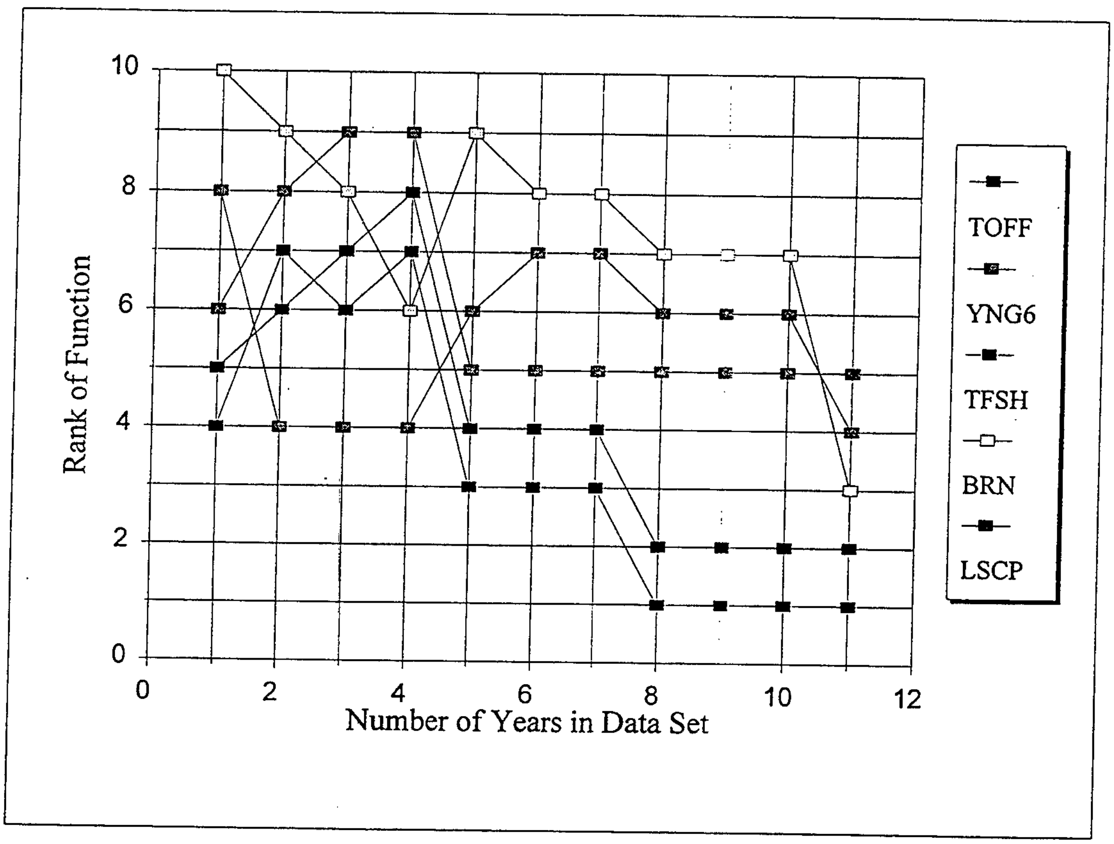

Figure 22. Number of years of data vs. rank of the best five transport functions, Clark Corner, AR

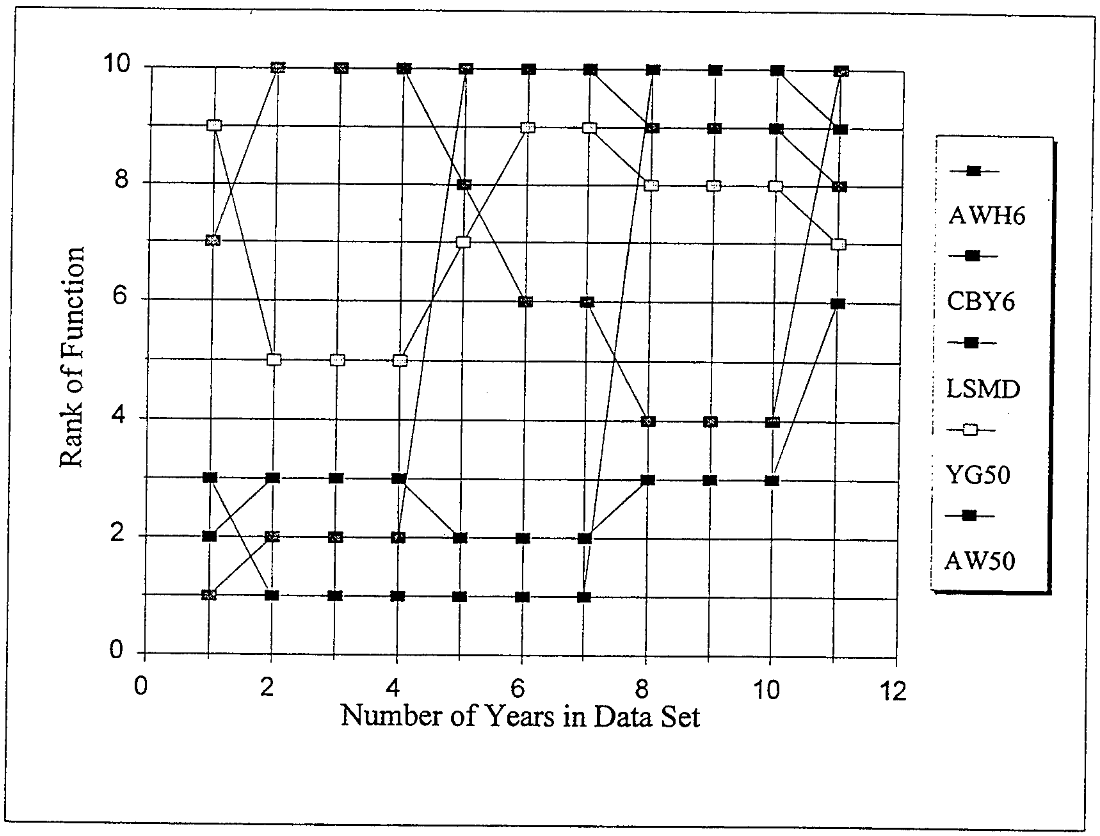

Figure 23. Number of years of data vs. rank of the other transport functions, Clark Corner, AR

among the top four ranked functions was less after seven to eight years.

So then, referring back to the research objective, i.e., to determine how much data are necessary, the answer is not entirely clear. A range can, however, be identified which does answer, in broad terms, the objective question. This range is from two to eight years for the St. Francis river data set.

This would indicate that if one were to collect eight years of sediment data, on a monthly basis, that this would constitute a sufficient data set to select the best sediment transport equation for predicting sediment transport in a given reach of the St. Francis River. This statistical evidence, however convincing, seems insufficient to stand alone as positive proof that eight years of record are all that is necessary.

Entropy Calculations

The work of the previous section defined a range (2-8 years) which encompassed the minimum amount of data necessary to determine the sediment transport function that best reproduced the observed data. However, while providing definitive guidance that has not previously been available, this range still seemed too broad. The value added associated with collection of the fully necessary data set was also not quantified. In order to narrow the range, earlier works in the application of the principle of entropy to water resources (see Chapter 1) were used as a basis to formulate an independent evaluation of the amount of data needed to provide the most information for the selected three stations in the St. Francis Basin. In addition, the principle of maximum entropy was applied to quantify the adequacy of the data sets.

To express the uncertainty in the computed sediment transport mathematically, it was assumed that the sediment transport is defined as a random variable X which has values of $x_1, x_2, \ldots x_n$, with probabilities $p_1, p_2, \ldots p_n$. $P(X=x_1)=p_1$, $P(X=x_2)=p_2, \ldots P(X=x_n)=P_n$. P(x) is the probability distribution of X satisfying

$$p(x) = (p_1, p_2, \ldots p_n); \sum_{i=1}^{n} p_i = 1, p_i \geq 0, i = 1, 2, \ldots n \tag{16}$$

After Shannon (1948a, 1948b), the entropy is defined as:

$$H(P) = H(X) = -\sum_{i=1}^{n} p_i \ln p_i \tag{17}$$

where H(P) is the entropy of the probability distribution $P = (p_1, p_2, \ldots p_n)$. Using equation (17), the incremental and total entropy could be computed. This would reveal the rate of information accumulation and the point of maximum information.

Singh (1992) has stated that entropy is a measure of the expected information content of space-time measurements. Since Jaynes (1957) has also stated that entropy and uncertainty are synonymous, this connection is not immediately obvious. However, it has been proven by many authors (Shannon, 1948; Jaynes, 1957; Singh, Fiorentino, 1992) that when entropy is maximized, the resulting data set is the least biased. Put another way, as long as entropy is increasing, additional samples reduce the bias of the population and are ever more valuable in that they provide more information. Once the entropy value stabilizes, additional information is less valuable. This may seem counter intuitive until one puts this statement in perspective. For example, let us assume that there are two data stations, station X and station Y. At station X there is perfect understanding of the processes in which we are interested in modeling. At station Y we know nothing of the processes in which we are interested in modeling. Furthermore, let us say that we are to be allowed to take a fixed number of additional data samples, Z. The question is, where to take them? Since we possess perfect knowledge at station X, there is no value in taking additional samples at station X. However, data samples taken at station Y would be extremely valuable, since we have no knowledge here. Each additional data sample at station Y would increase our understanding of the processes there, up to a point. That point is the point of maximum total entropy.

Therefore, the data sets for Fisk, Wilhelmina and Clark Corner were analyzed by looking at the incremental total entropy after each year of data were collected. The point at which the entropy definitely ceased to increase would define the minimum amount of sediment data necessary that provided the maximum amount of information and least biased population. If the entropy continually increased, then the data set(s) would not contain the maximum amount of information.

The procedure for calculating the entropy at each station consisted of several steps. First, the data to be used in the calculation were selected. These data consisted of the best calculated values for each station, best being defined as the transport function that was the best predictor based on the regression analyses performed above. The selected transport functions were Yang-HEC6 for the Fisk, Station, Brownlie for the Wilhelmina station and Toffaleti-Schoklitsch for the Clark Corner station. Next, the data were presented as a discrete distribution. This was generated by dividing the data into intervals. The number of intervals selected was based on trying to achieve a reasonable number of intervals. If too few were selected, the data would all be clumped in these intervals and the distribution might well be biased. Too many intervals would lead to unnecessary calculations without changing the actual results. The Fisk station seemed to offer no real problems along these lines. The data values fit within a range of 0-4000. Therefore, forty intervals resulted in an interval width of 100 (Figures 20-34). The other two stations offered a bit of problem in that the range of values were much greater. At Wilhelmina, the data values fit within a range of 0-26,000 and at Clark Corner ranged from 0-38,000. Therefore, the data at these stations were distributed using thirty and fifty-two intervals at Wilhelmina and forty-five and seventy-six at Clark Corner. The different number of intervals were used to investigate sensitivity to this decision. The number of intervals changed the absolute value of the entropy, but not the trends. The higher number of intervals were selected for analysis and are presented in the figures showing the transport function's distribution at Wilhelmina and Clark Corner (Figures 35-56).

The segmented data were plotted versus various probability distributions. Several distributions initially seemed to fit the data well, notably the Lognormal, Gamma and Weibull. On closer inspection, the Weibull distribution was selected as the most representative of the three distributions. Figures 24-34 depict the Yang-HEC6 computed values (best predictor based on regression analysis) divided into forty intervals and fitted to the Weibull distribution for the Fisk, MO, Station. Figures 35-45 depict the Brownlie computed values (best predictor based on regression analysis) divided into fifty-two intervals and fitted to the Weibull distribution for the Wilhelmina Cutoff station. Figures 46-56 depict the Toffaleti-Schoklitsch computed values (best predictor based on regression analysis) divided into seventy-six intervals and fitted to the Weibull distribution for the Clark Corner Cutoff station. Next, the number of occurrences in each interval, for each data segment (i.e., data including one year, two years, etc.) were tabulated. These were input into a Quattro-Pro spreadsheet and the probability of occurrence, p_i, for each interval calculated by dividing the number of occurrences by the total number of data points. Using these probabilities and equation (17), the total entropy was calculated for each data segment. In the case of Wilhelmina and Clark Corner, two sets of computations were made using the two different intervals. These entropy values (maximums boldface) and their variation with the amount of data collected are shown in Tables 15 and 16.

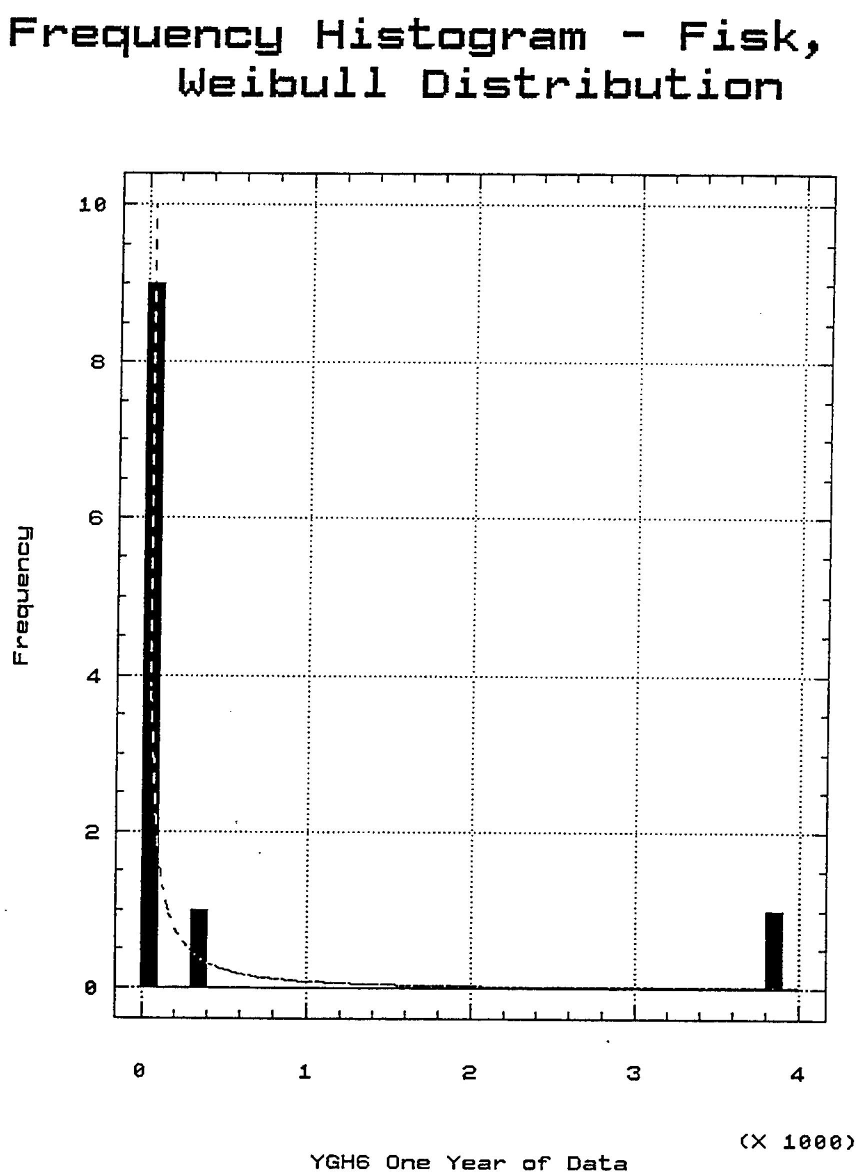

Figure 24. Yang-HEC6 transport function results fitted to the Weibull distribution for one year of data, Fisk, MO

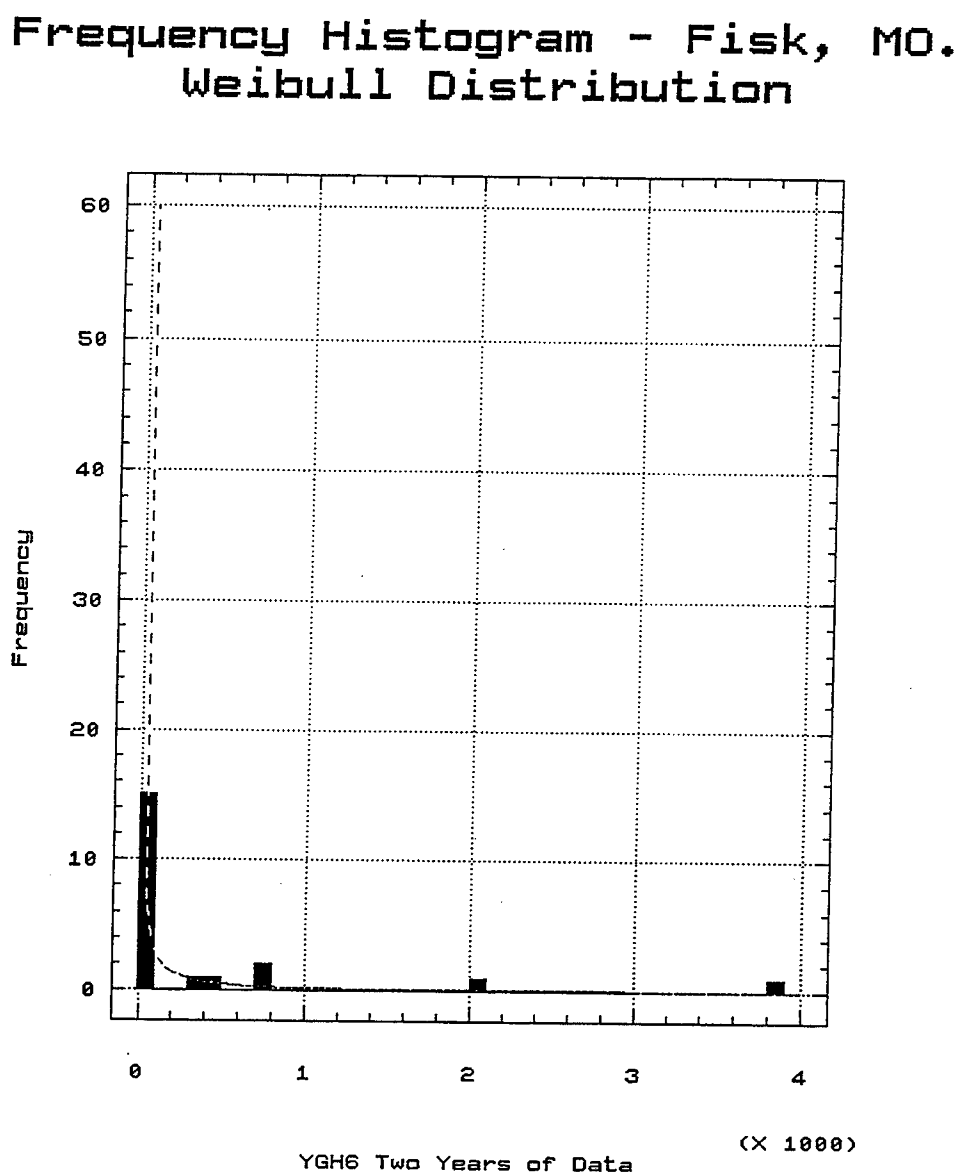

Figure 25. Yang-HEC6 transport function results fitted to the Weibull distribution for two years of data, Fisk, MO

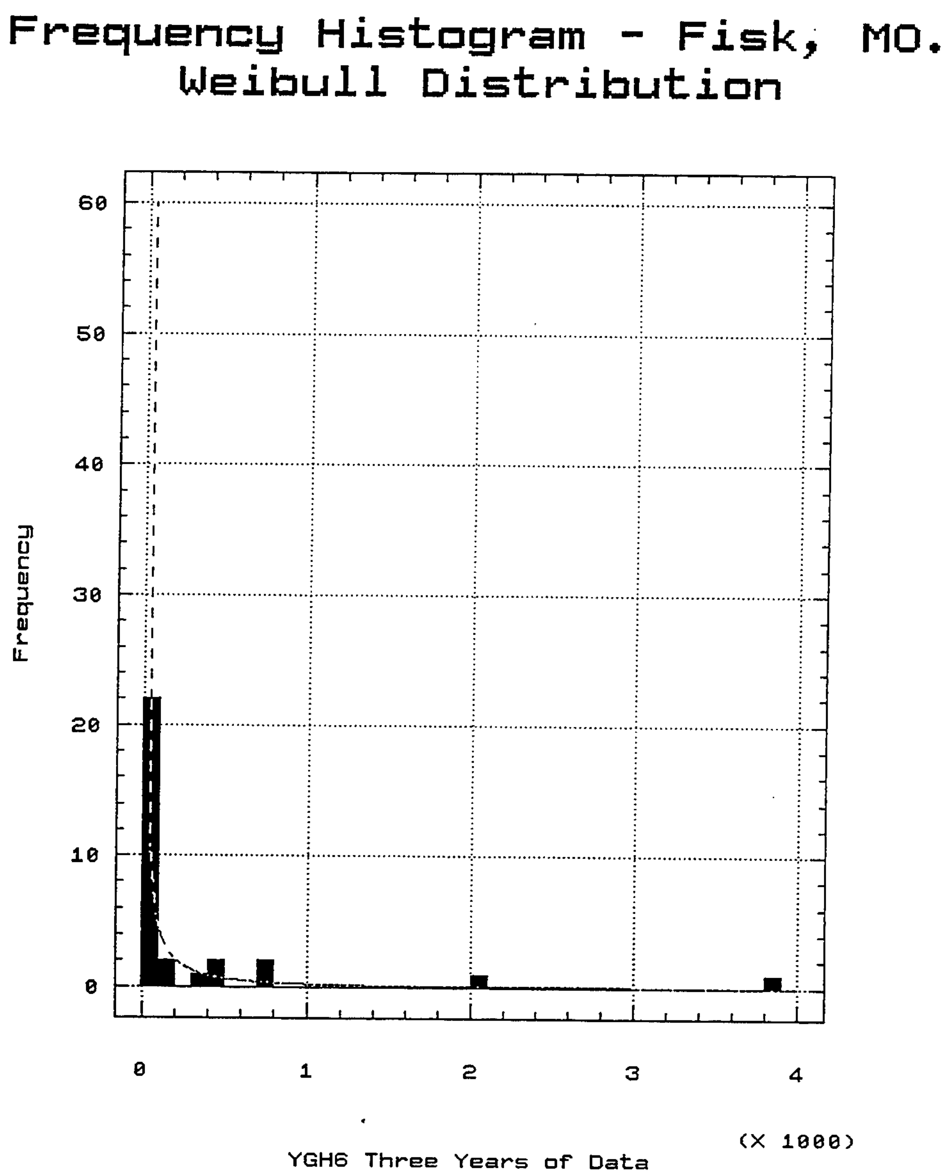

Figure 26. Yang-HEC6 transport function results fitted to the Weibull distribution for three years of data, Fisk, MO

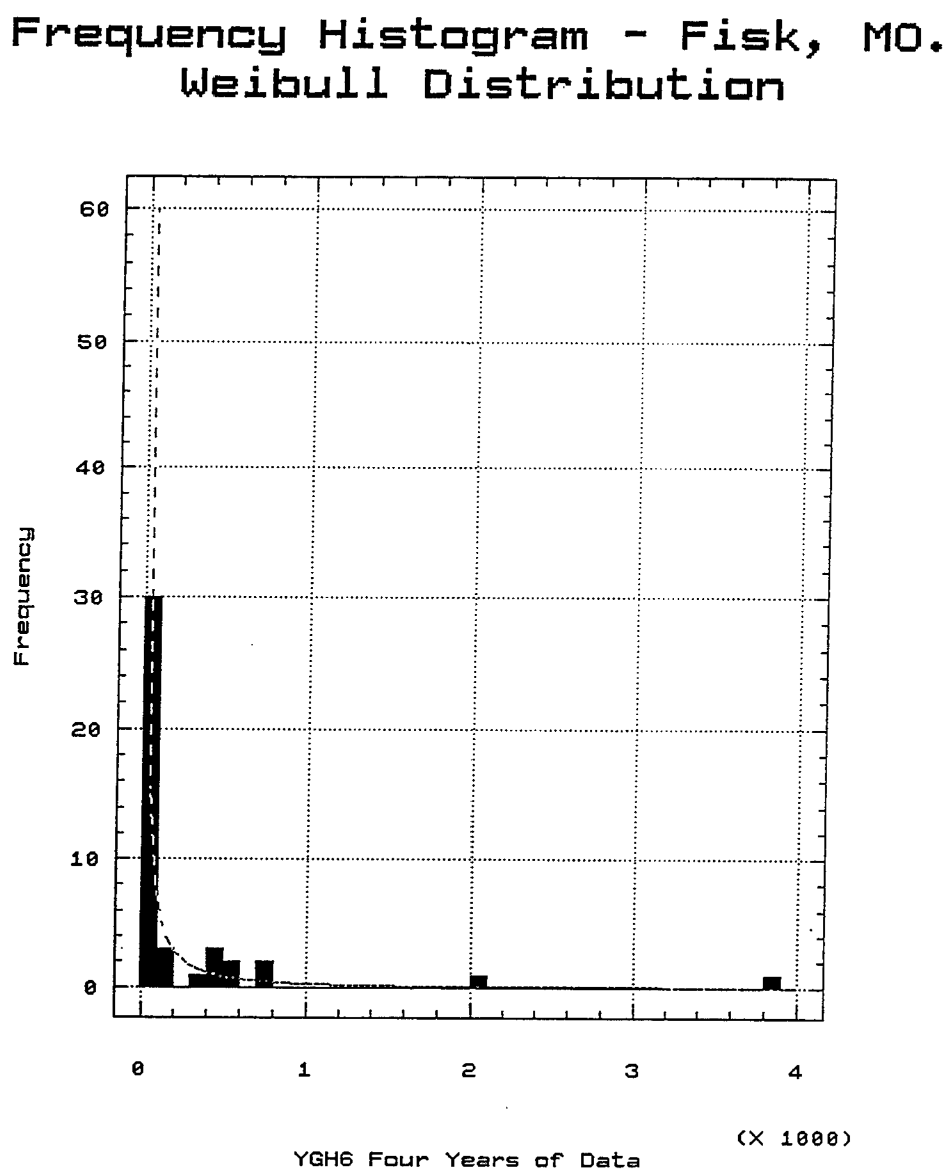

Figure 27. Yang-HEC6 transport function results fitted to the Weibull distribution for four years of data, Fisk, MO

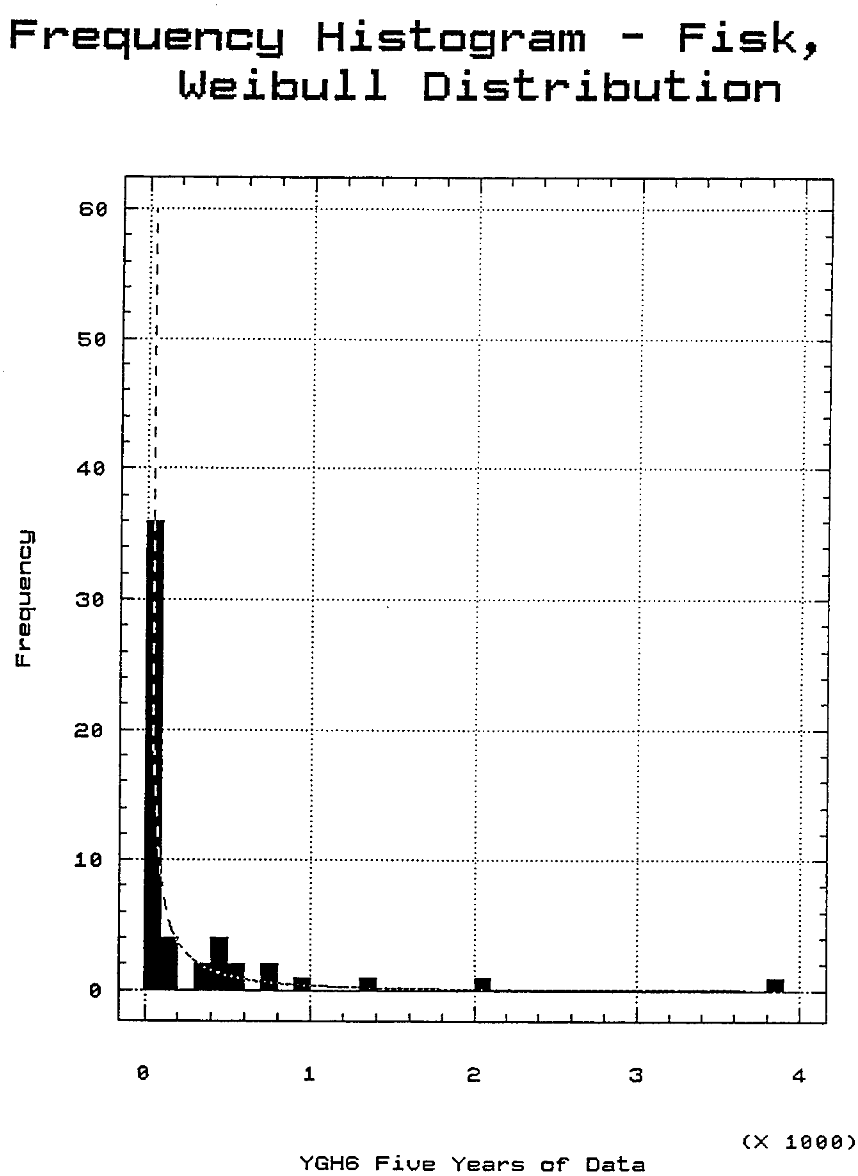

Figure 28. Yang-HEC6 transport function results fitted to the Weibull distribution for five years of data, Fisk, MO

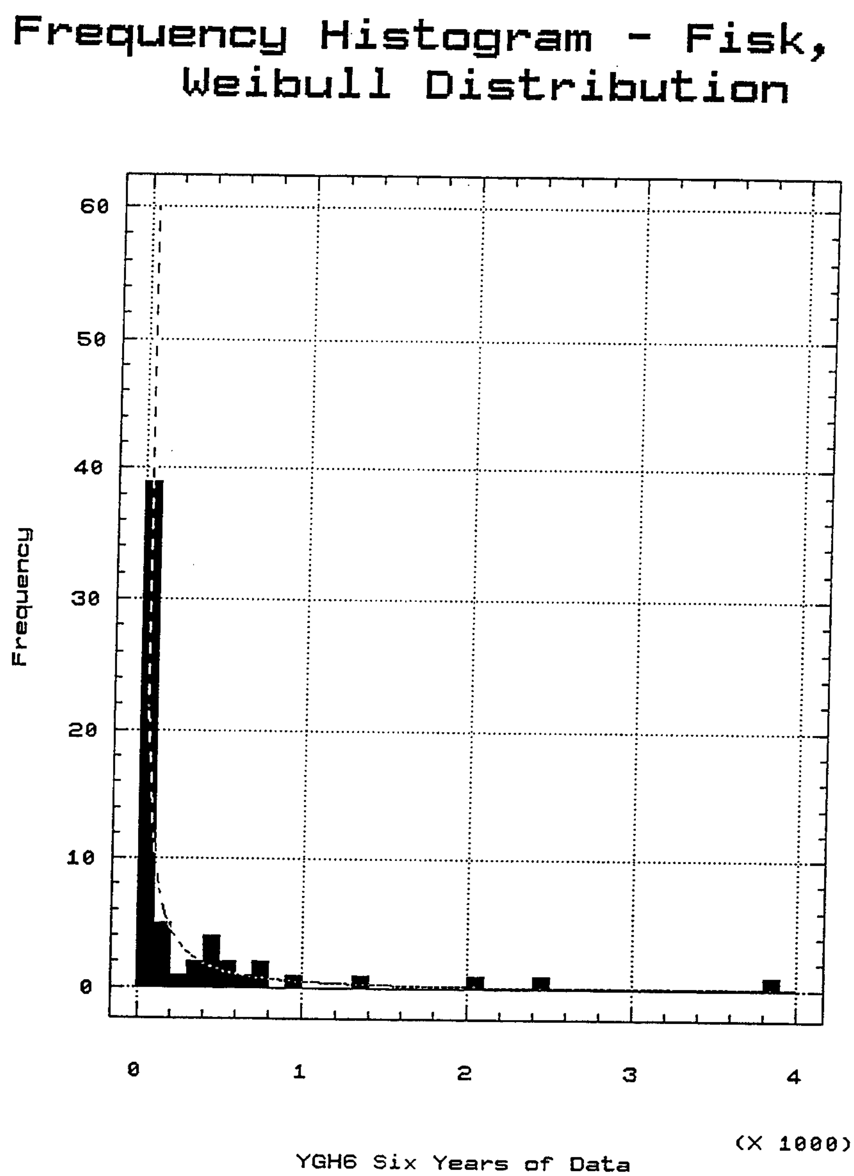

Figure 29. Yang-HEC6 transport function results fitted to the Weibull distribution for six years of data, Fisk, MO

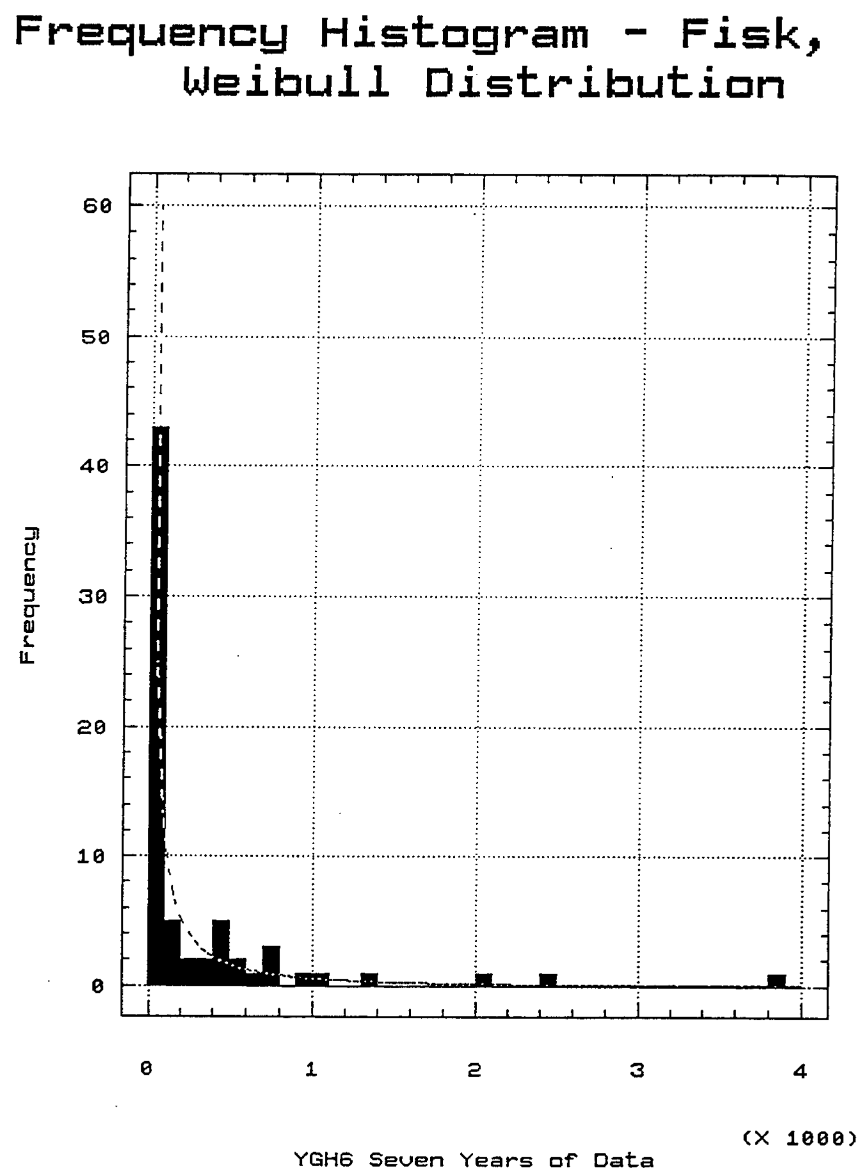

Figure 30. Yang-HEC6 transport function results fitted to the Weibull distribution for seven years of data, Fisk, MO

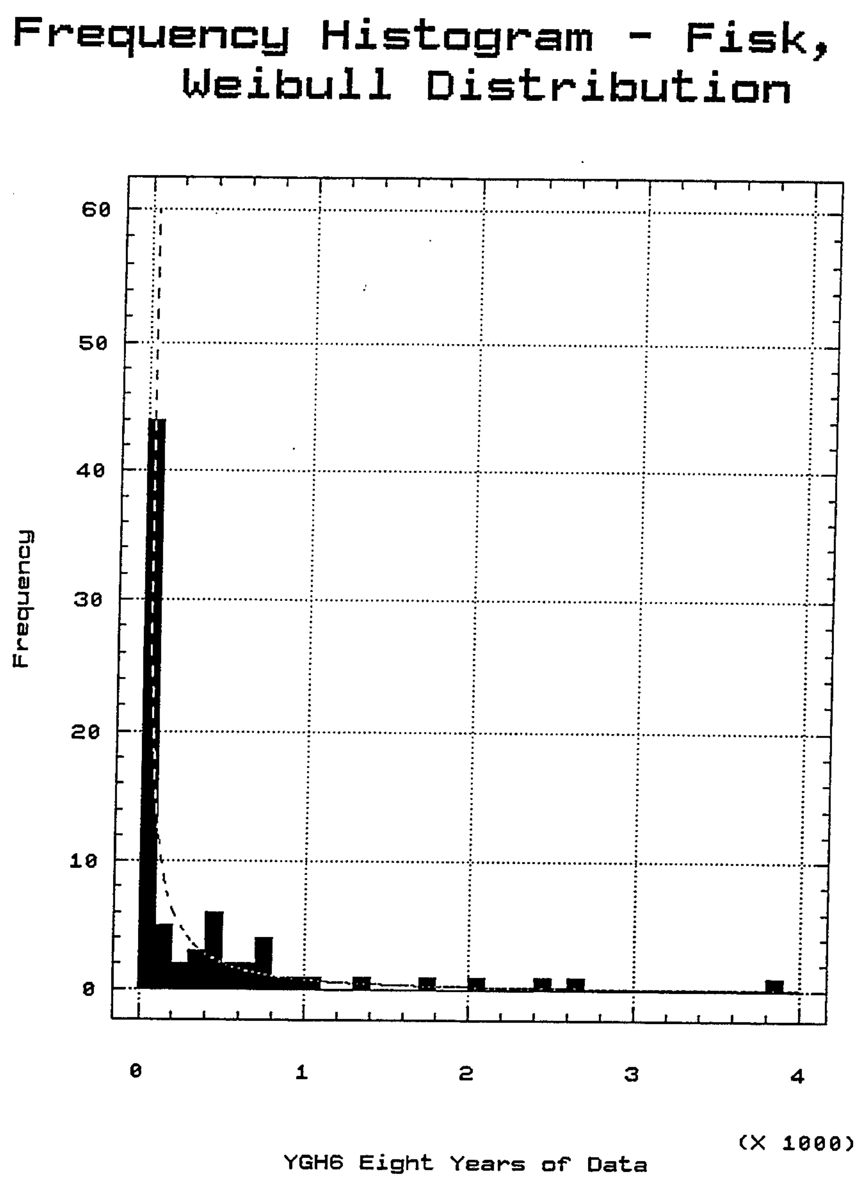

Figure 31. Yang-HEC6 transport function results fitted to the Weibull distribution for eight years of data, Fisk, MO

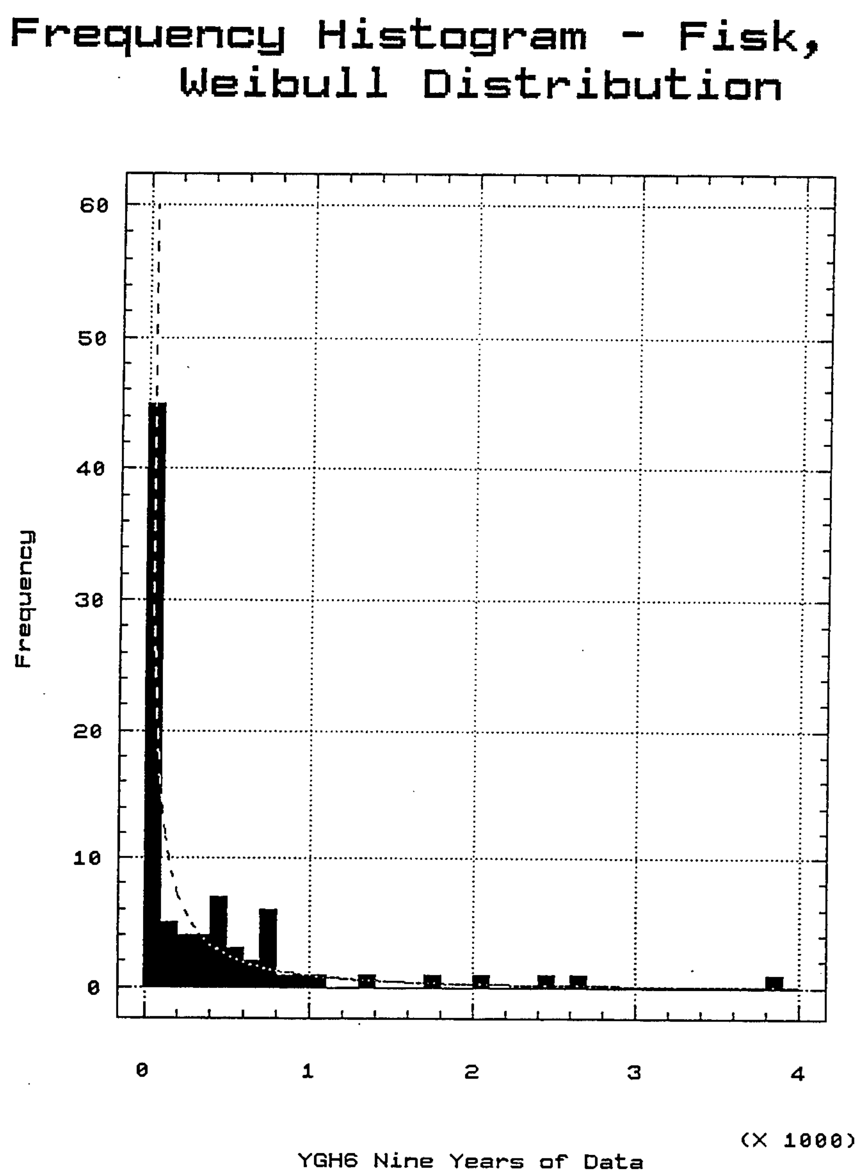

Figure 32. Yang-HEC6 transport function results fitted to the Weibull distribution for nine years of data, Fisk, MO

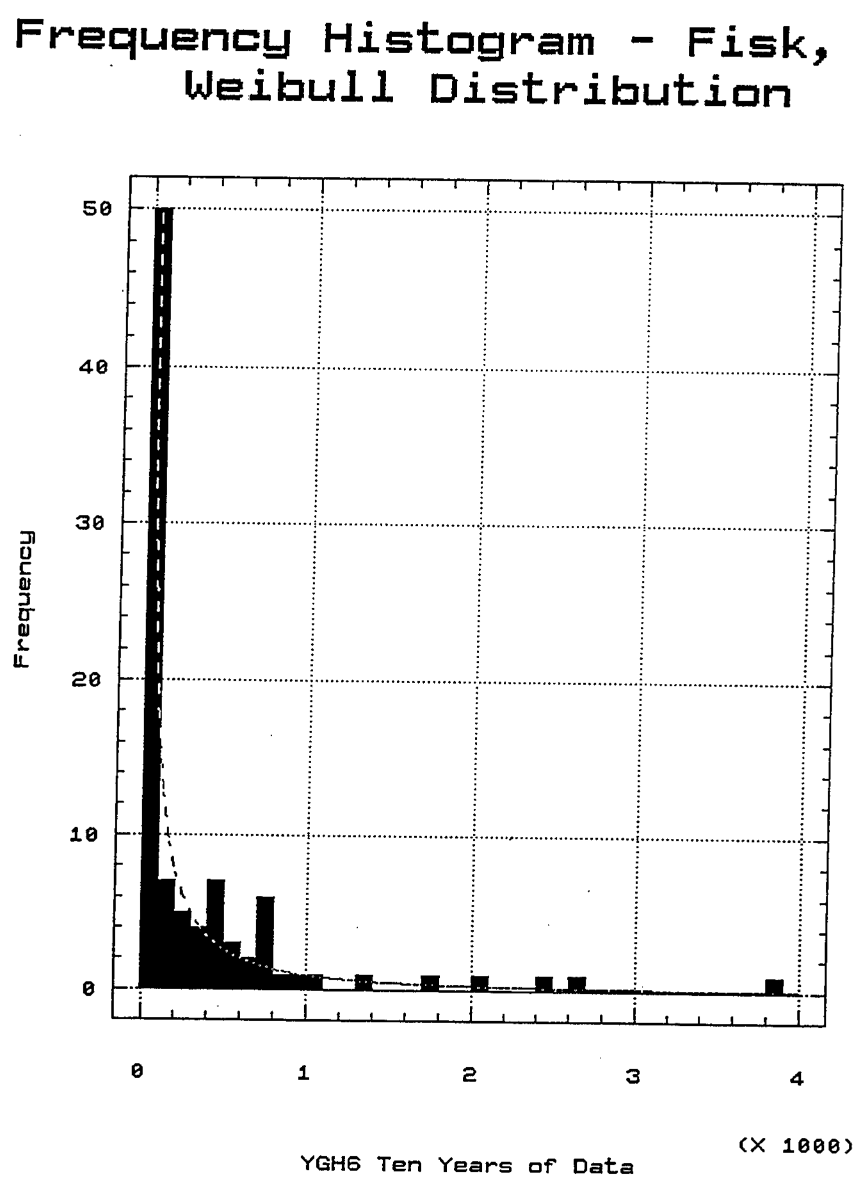

Figure 33. Yang-HEC6 transport function results fitted to the Weibull distribution for ten years of data, Fisk, MO

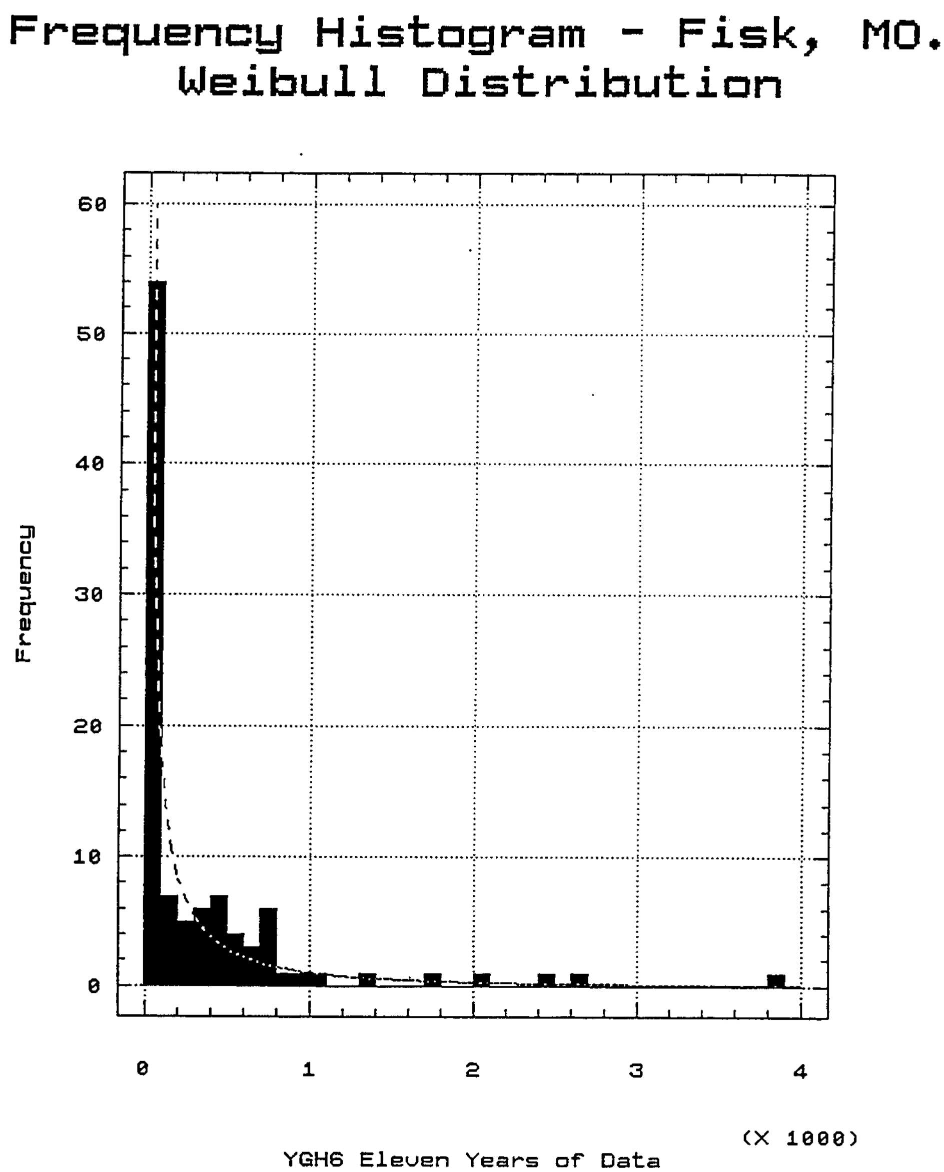

Figure 34. Yang-HEC6 transport function results fitted to the Weibull distribution for eleven years of data, Fisk, MO

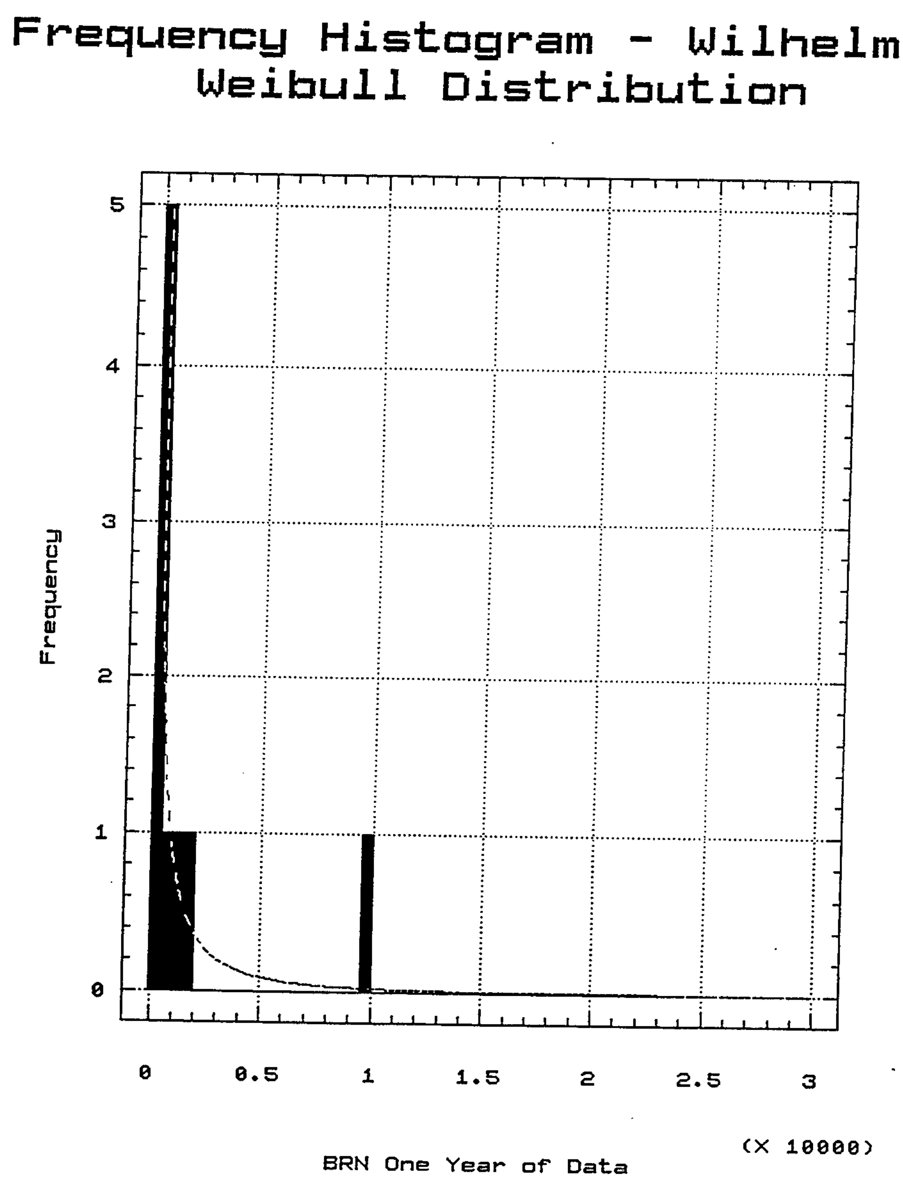

Figure 35. Brownlie transport function results fitted to the Weibull distribution for one year of data, Wilhelmina, MO

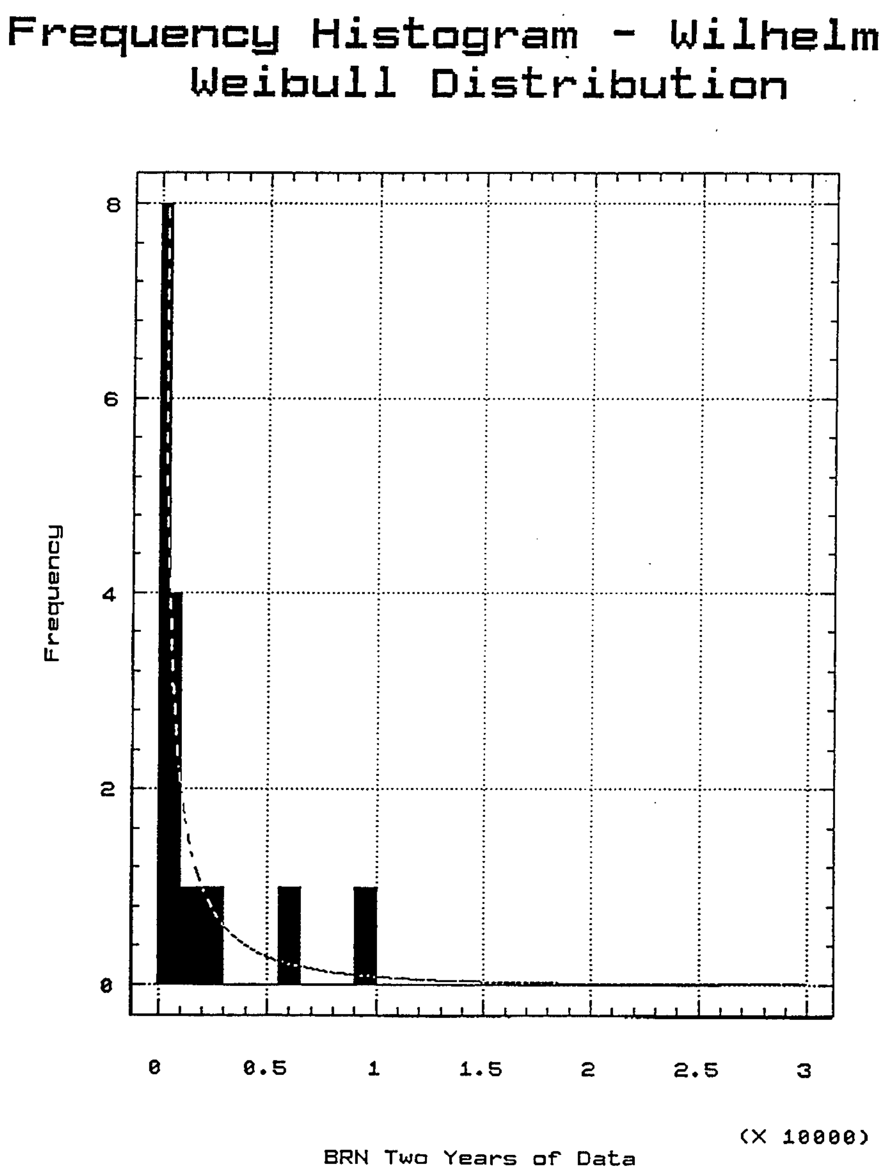

Figure 36. Brownlie transport function results fitted to the Weibull distribution for two years of data, Wilhelmina, MO

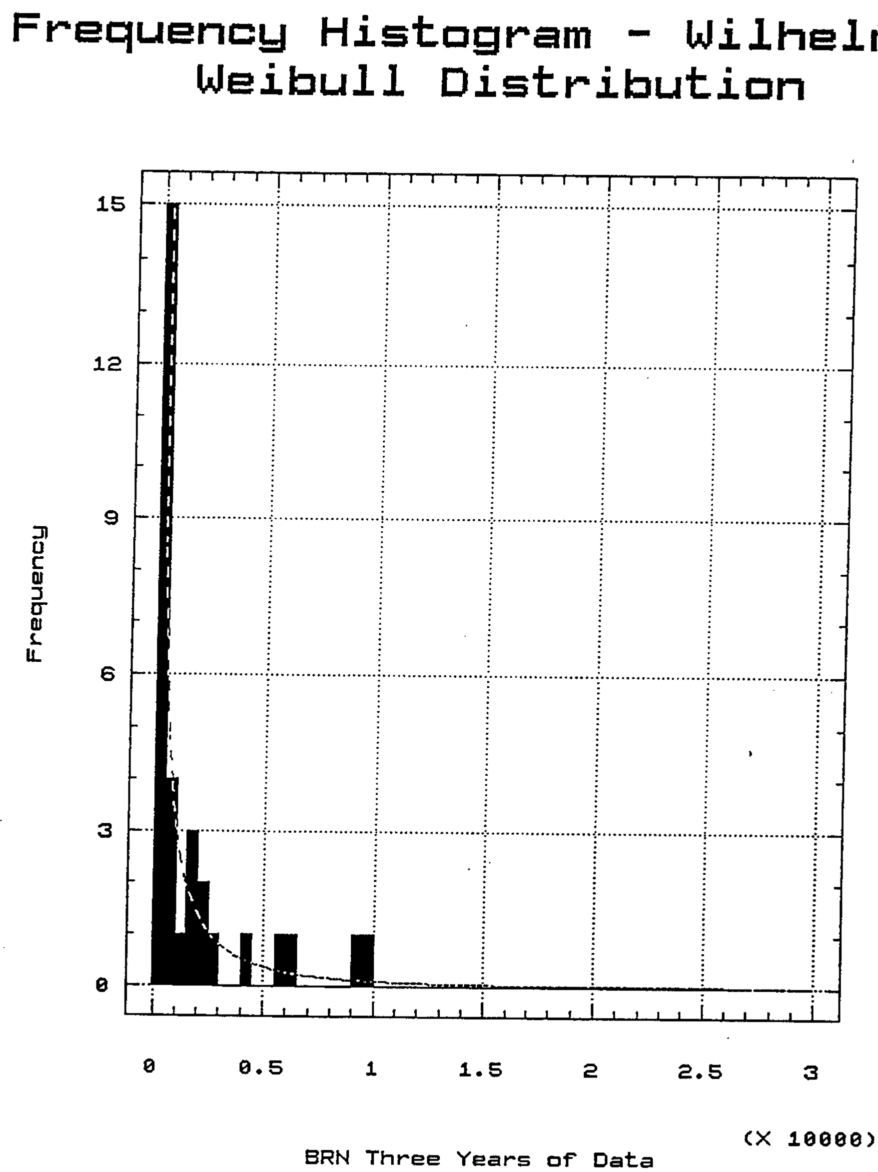

Figure 37. Brownlie transport function results fitted to the Weibull distribution for three years of data, Wilhelmina, MO

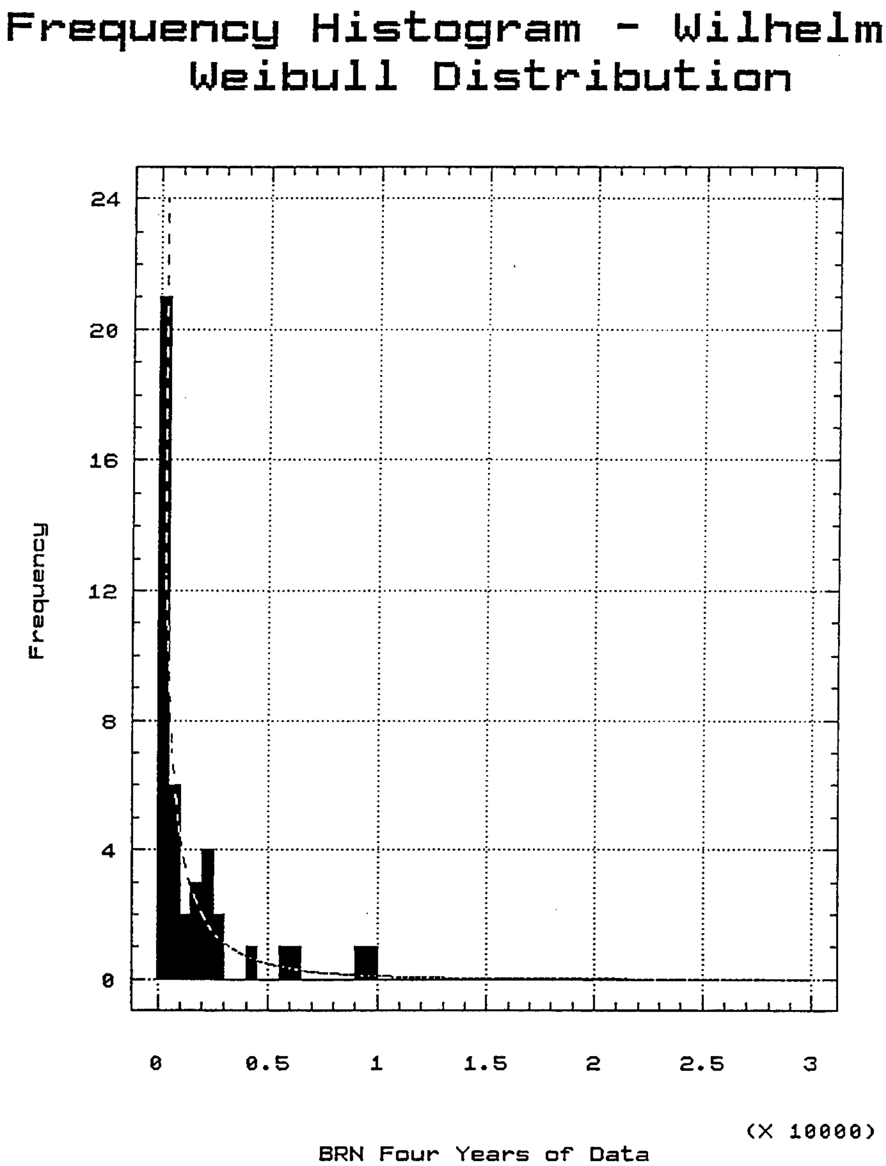

Figure 38. Brownlie transport function results fitted to the Weibull distribution for four years of data, Wilhelmina, MO

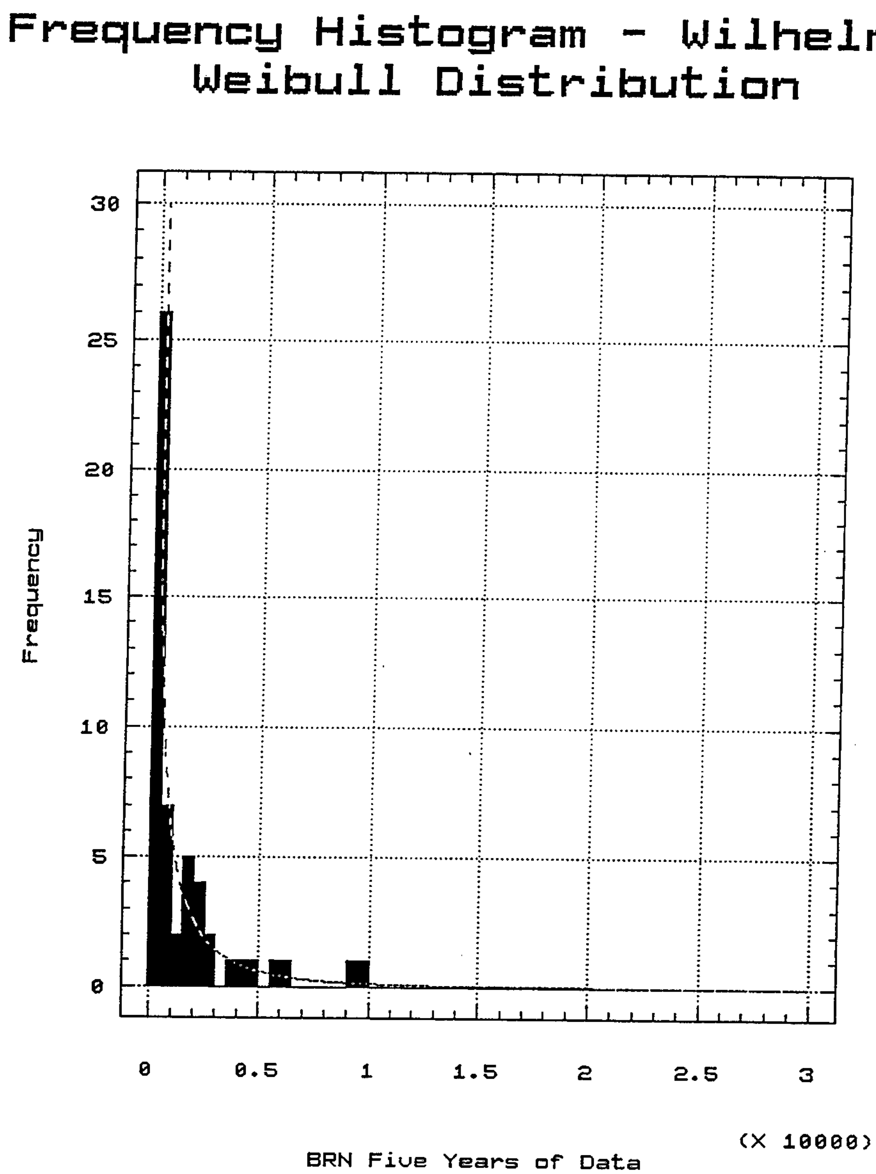

Figure 39. Brownlie transport function results fitted to the Weibull distribution for five years of data, Wilhelmina, MO

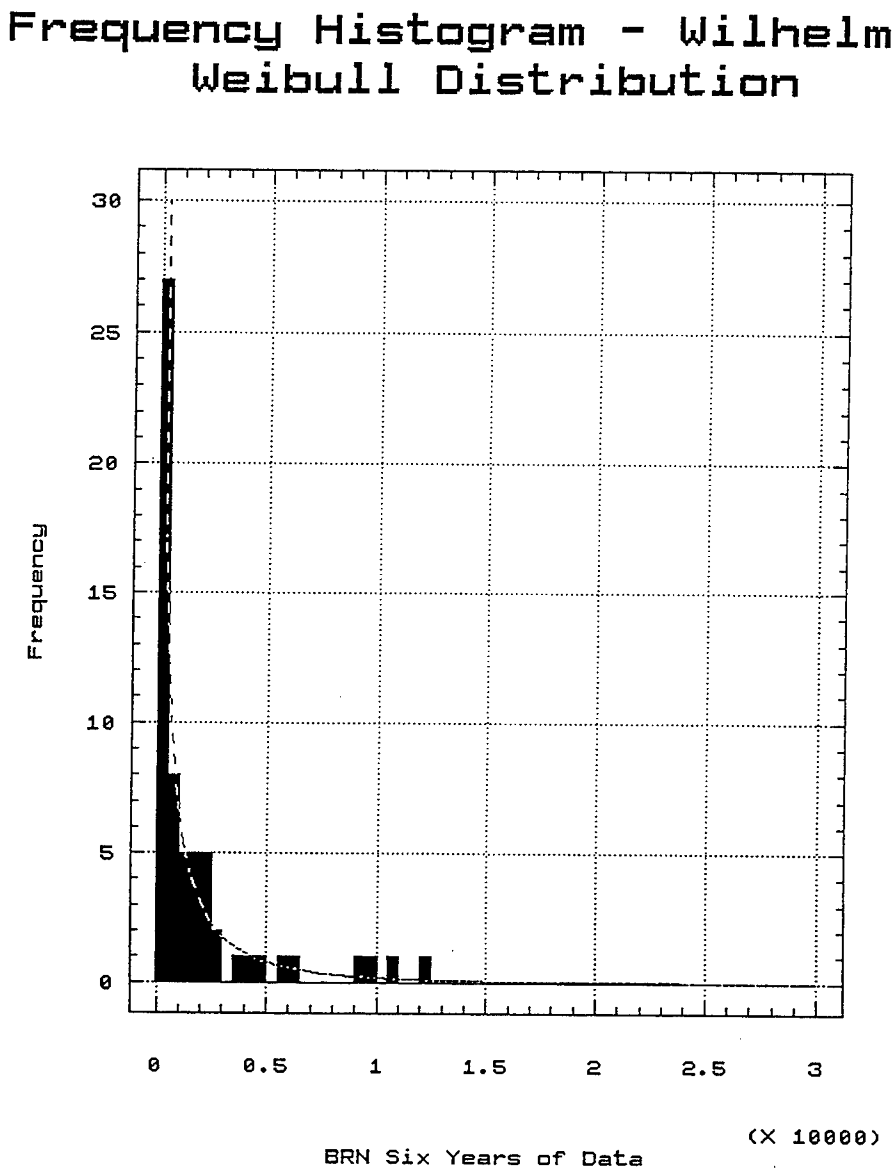

Figure 40. Brownlie transport function results fitted to the Weibull distribution for six years of data, Wilhelmina, MO

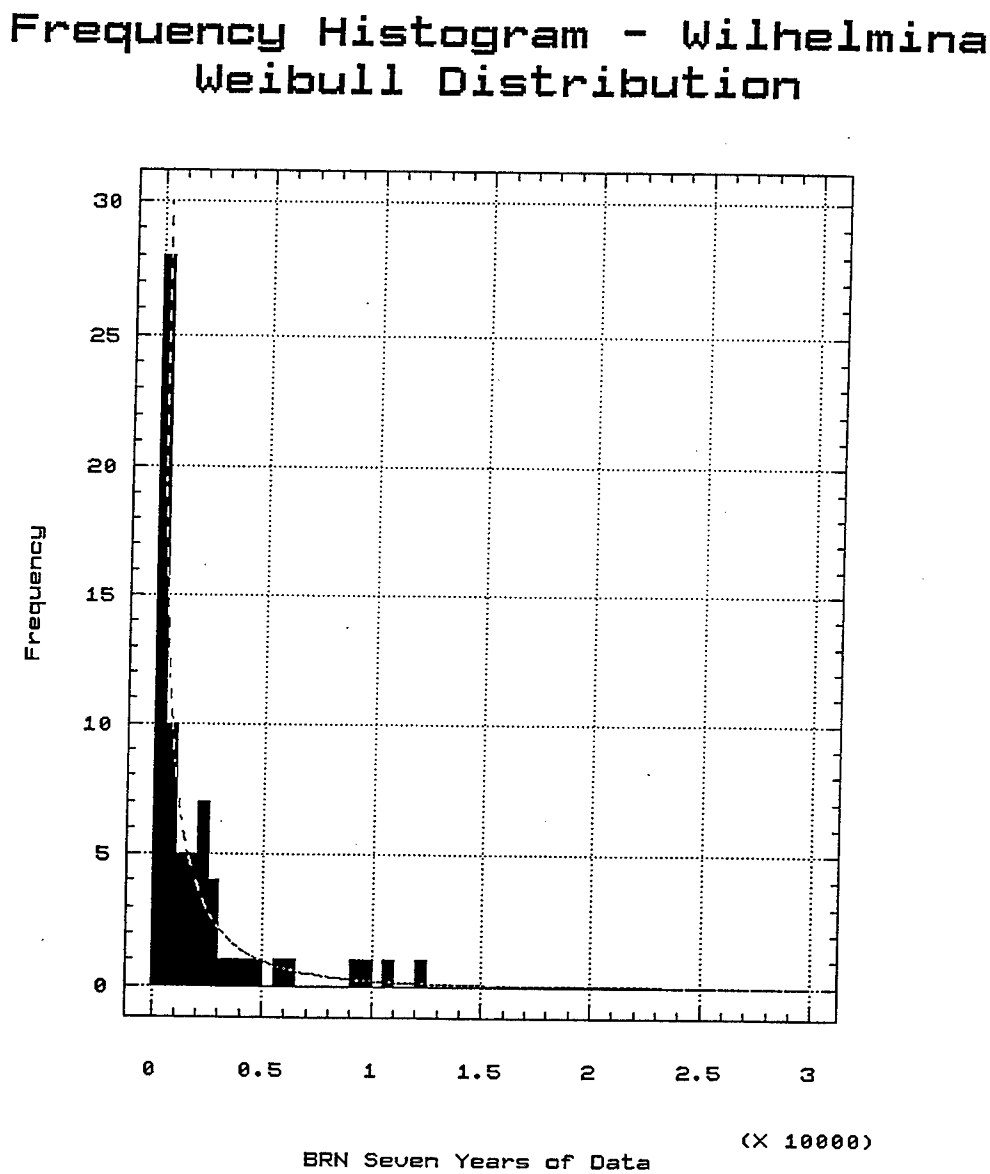

Figure 41. Brownlie transport function results fitted to the Weibull distribution for seven years of data, Wilhelmina, MO

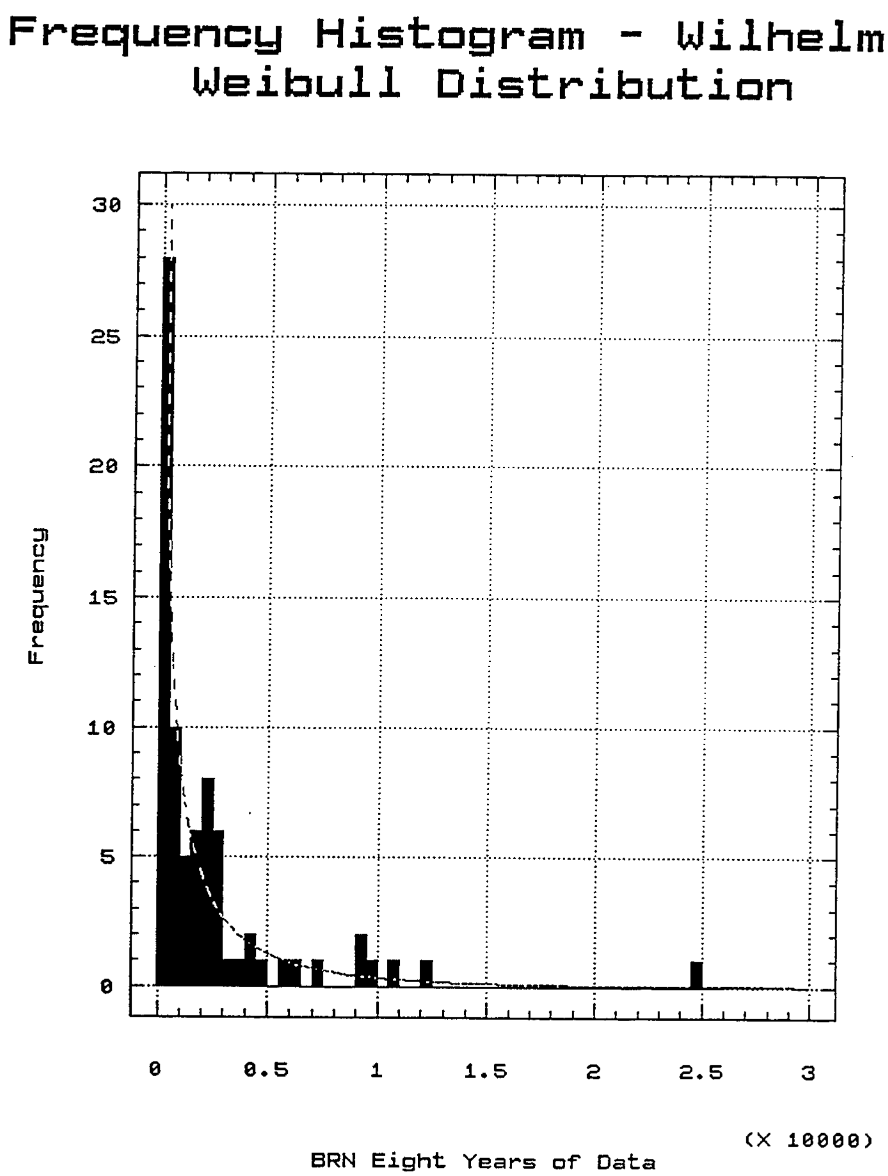

Figure 42. Brownlie transport function results fitted to the Weibull distribution for eight years of data, Wilhelmina, MO

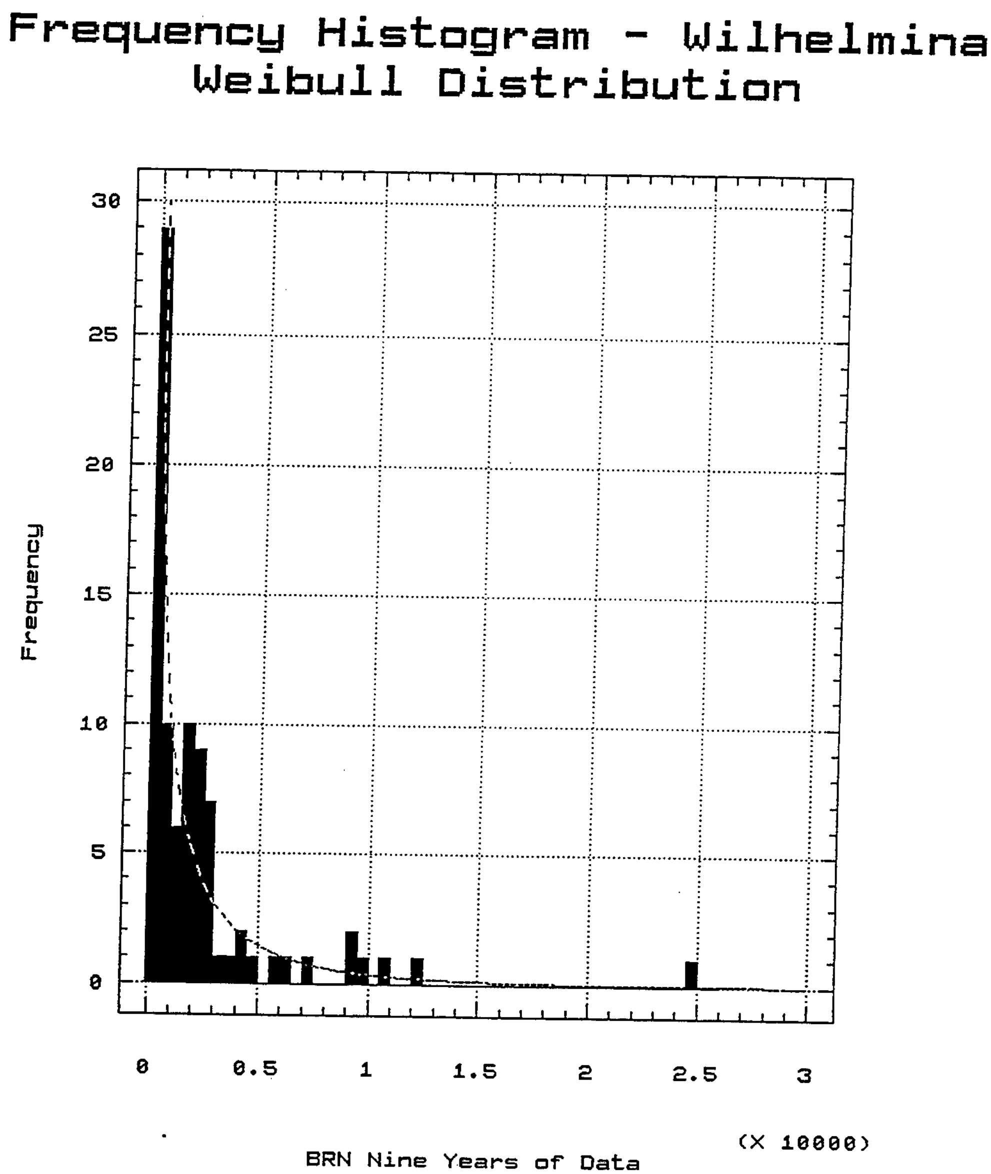

Figure 43. Brownlie transport function results fitted to the Weibull distribution for nine years of data, Wilhelmina, MO

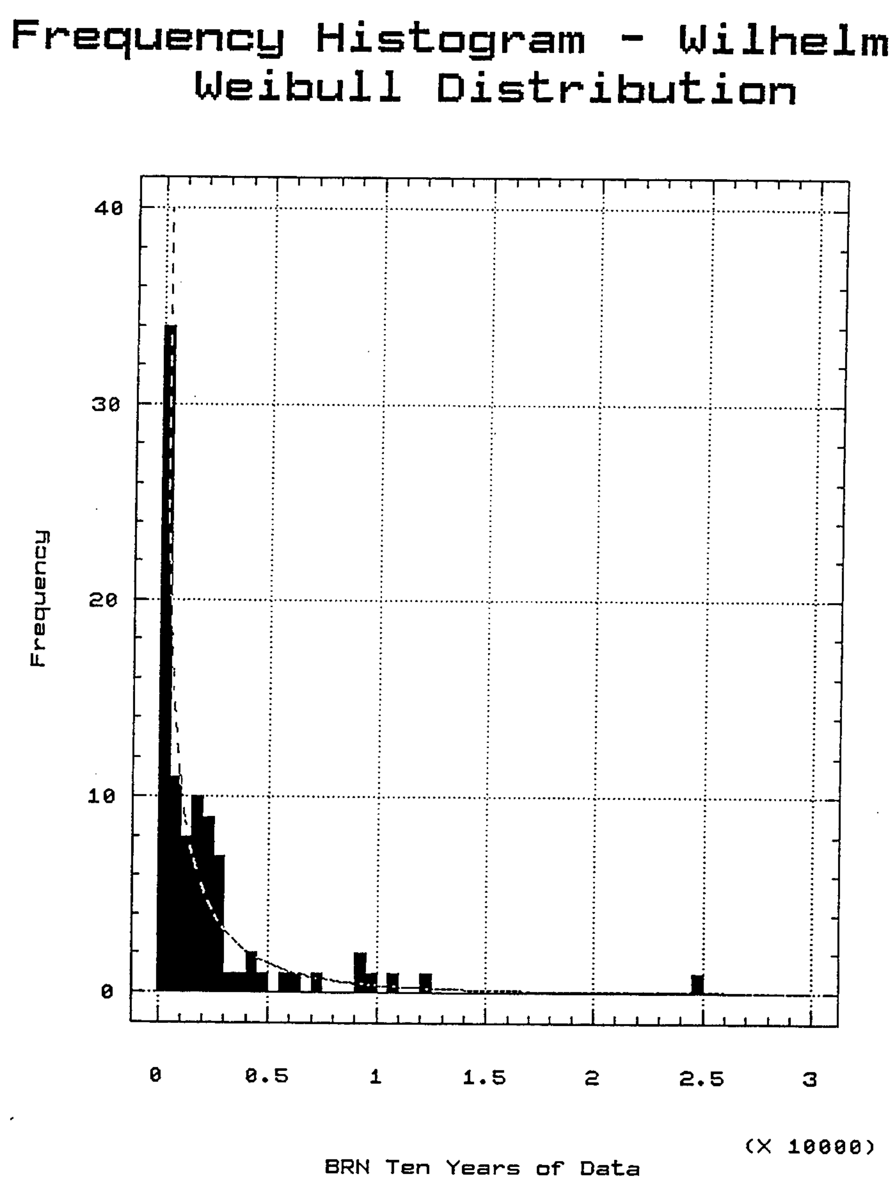

Figure 44. Brownlie transport function results fitted to the Weibull distribution for ten years of data, Wilhelmina, MO

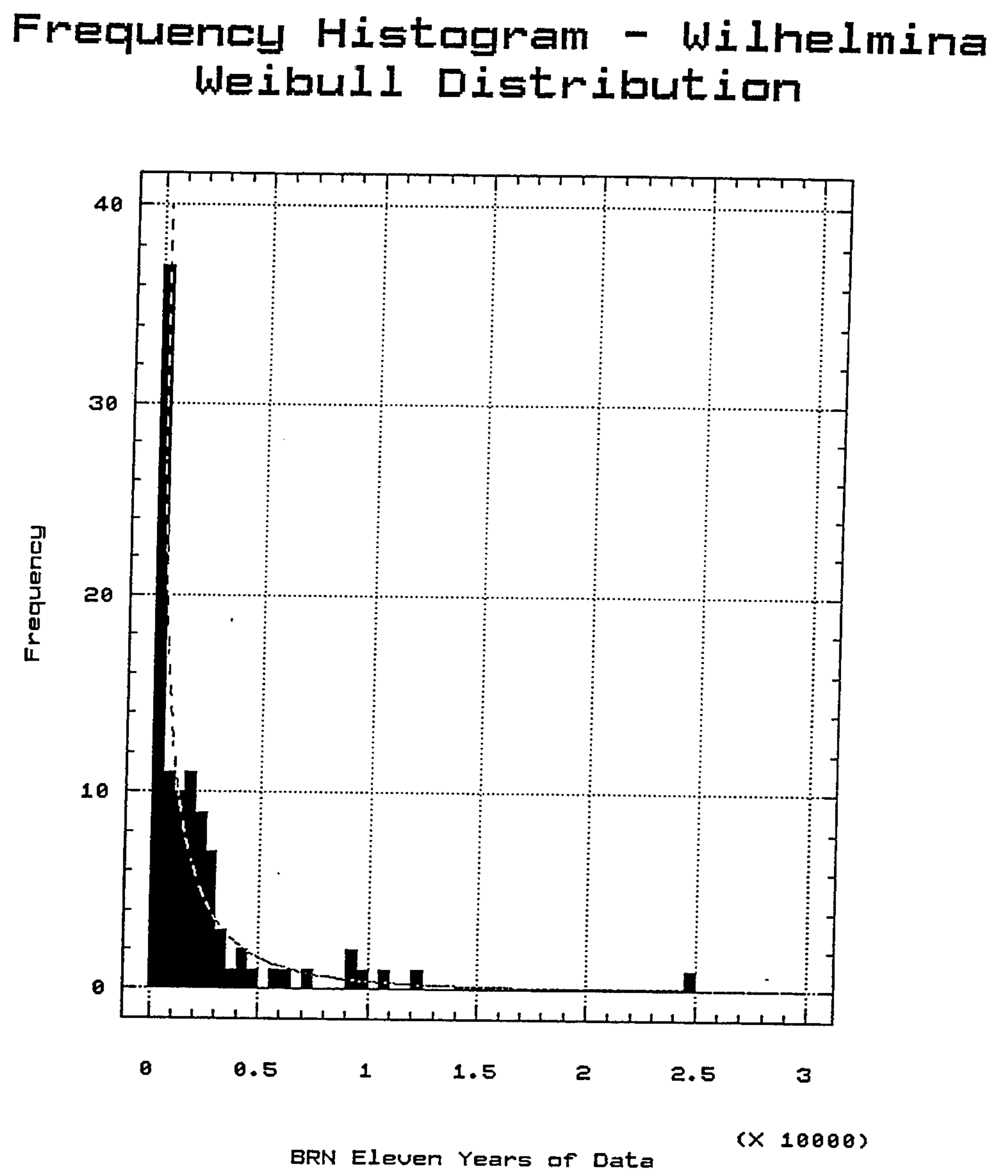

Figure 45. Brownlie transport function results fitted to the Weibull distribution for eleven years of data, Wilhelmina, MO

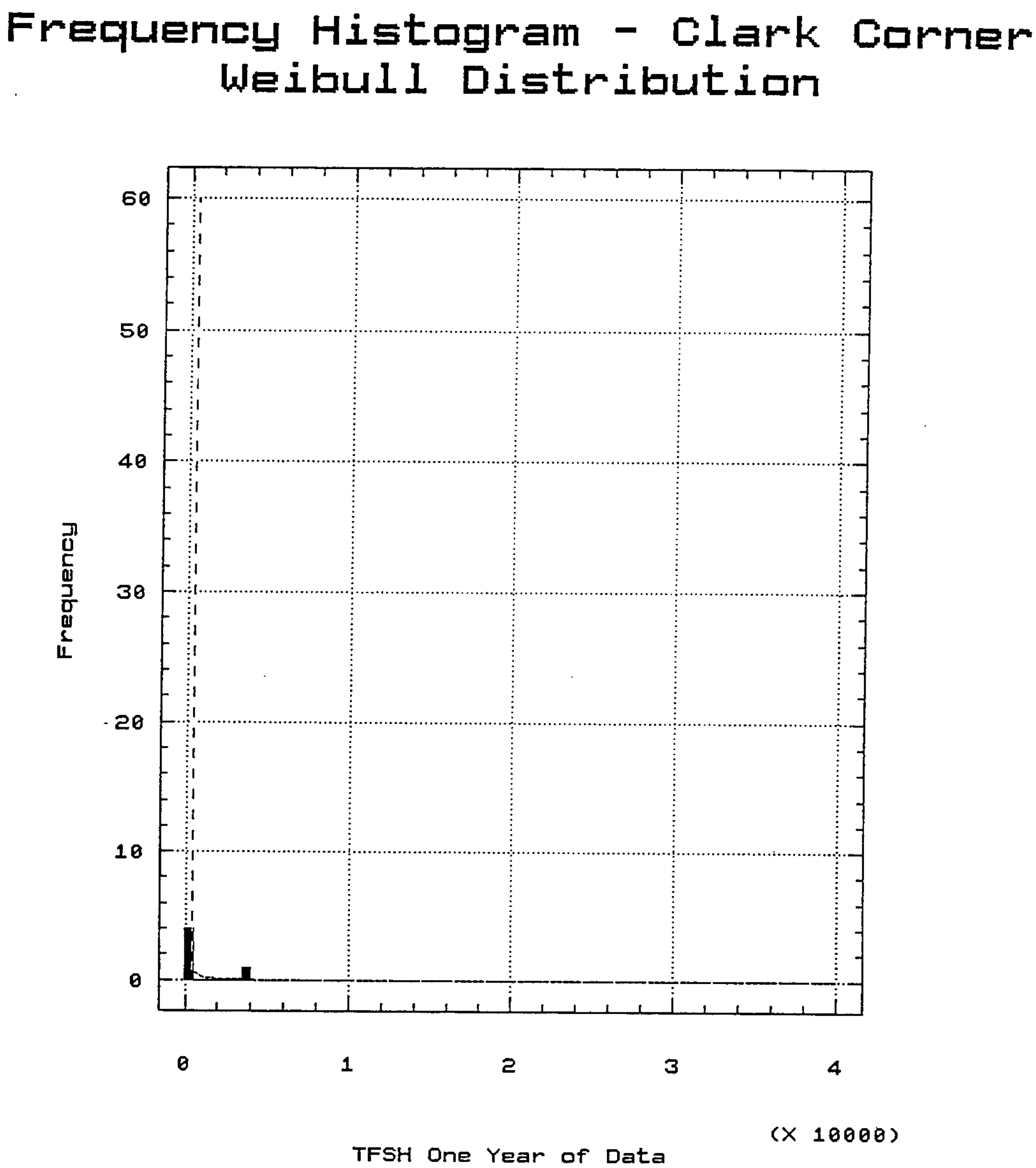

Figure 46. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for one year of data, Clark Corner, AR

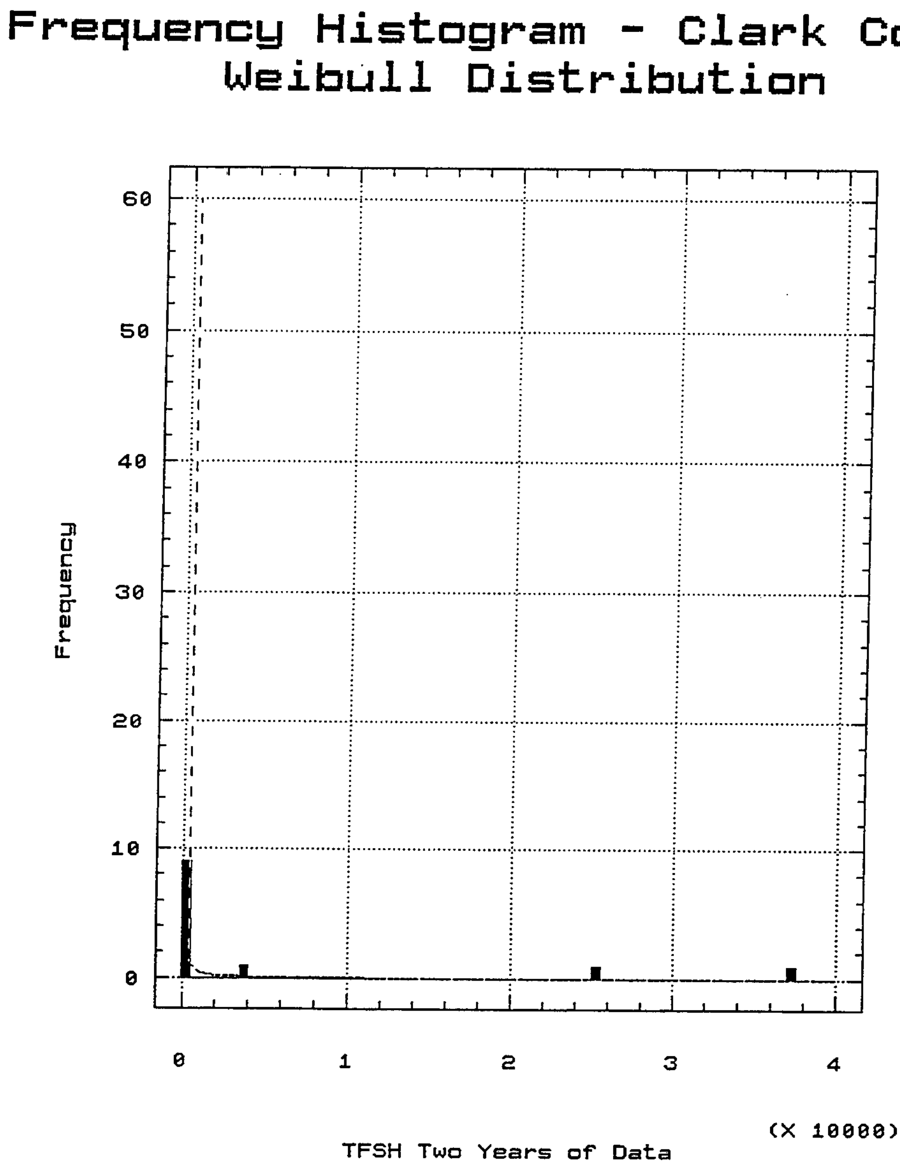

Figure 47. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for two years of data, Clark Corner, AR

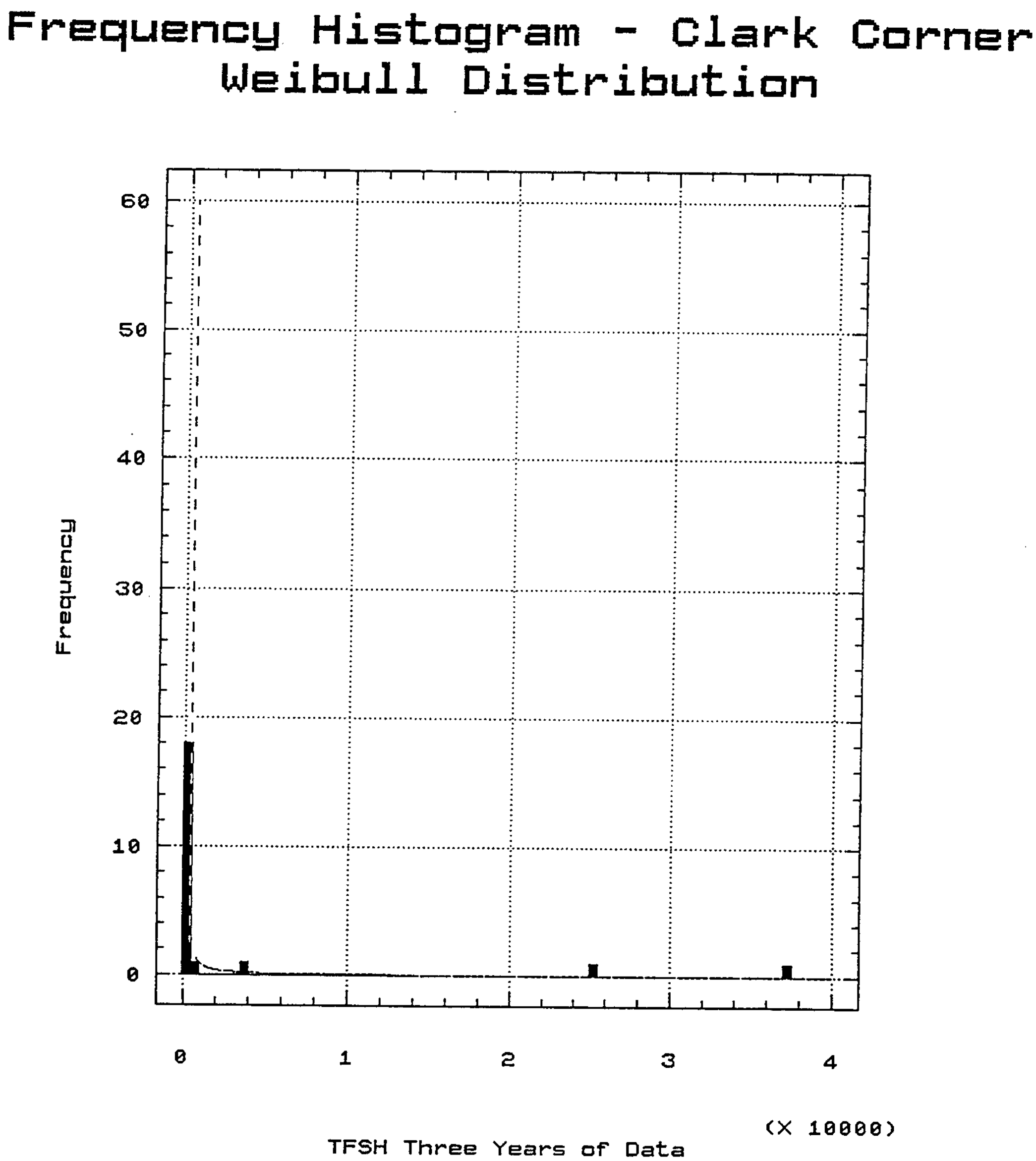

Figure 48. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for three years of data, Clark Corner, AR

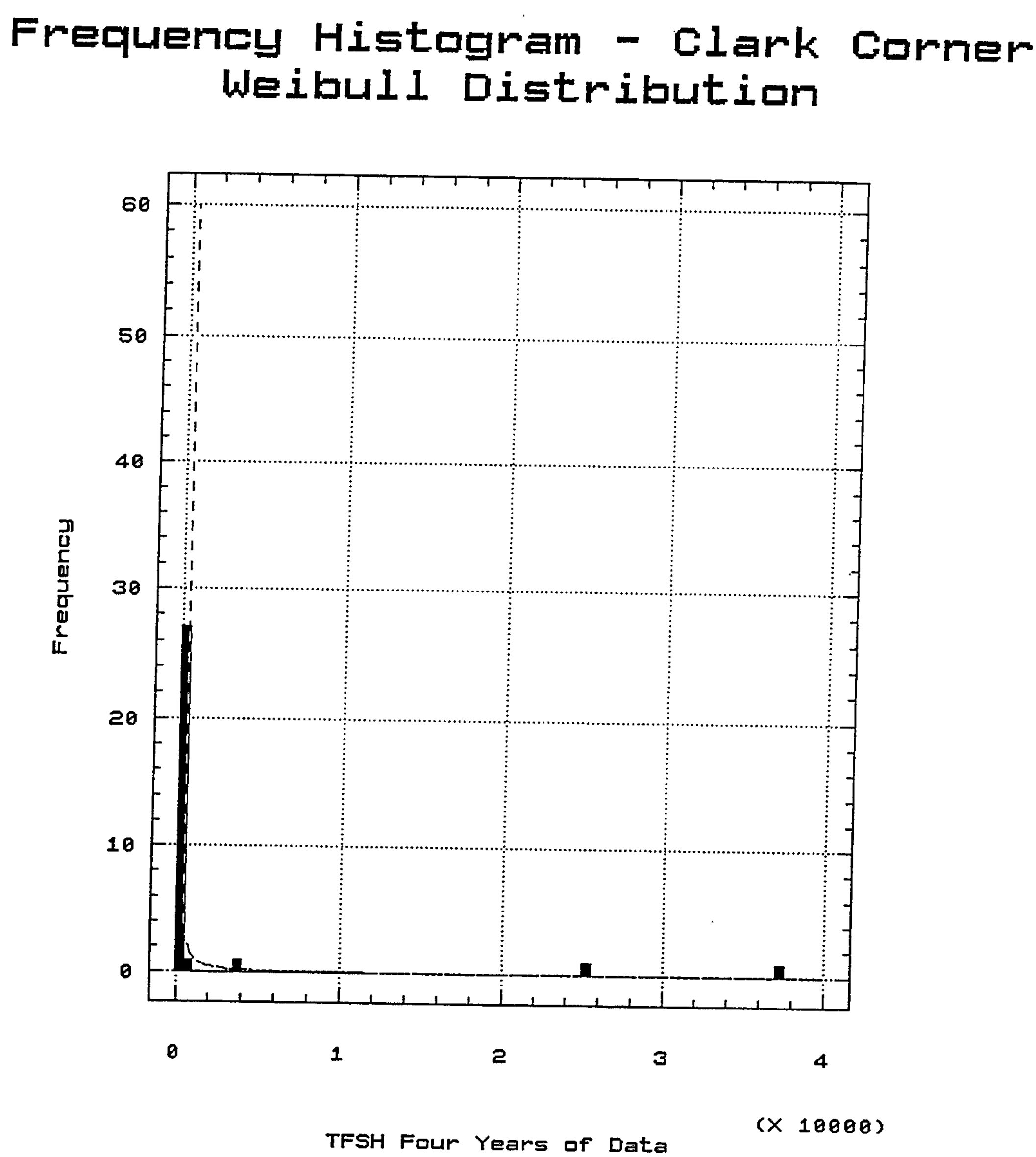

Figure 49. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for four years of data, Clark Corner, AR

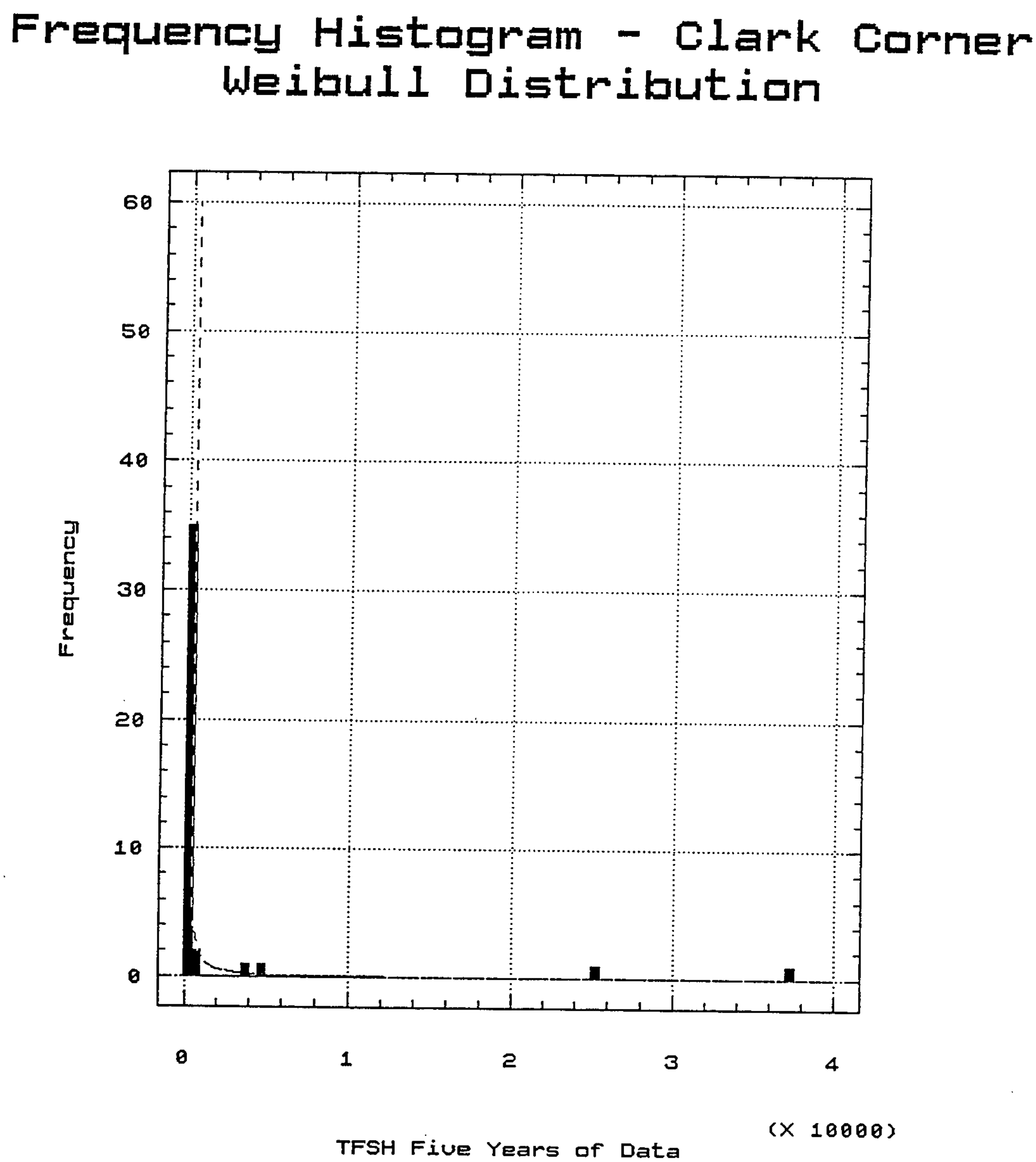

Figure 50. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for five years of data, Clark Corner, AR

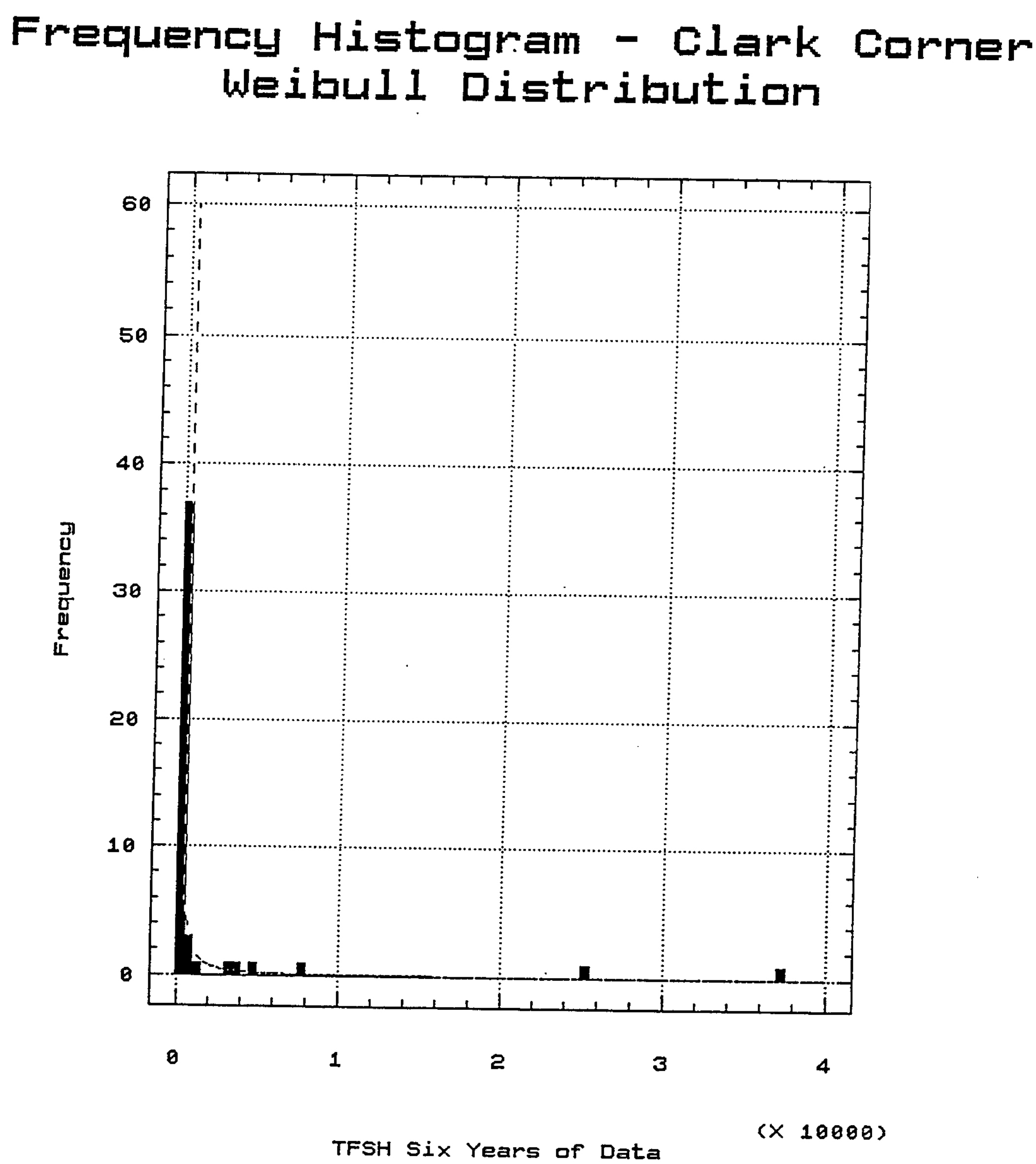

Figure 51. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for six years of data, Clark Corner, AR

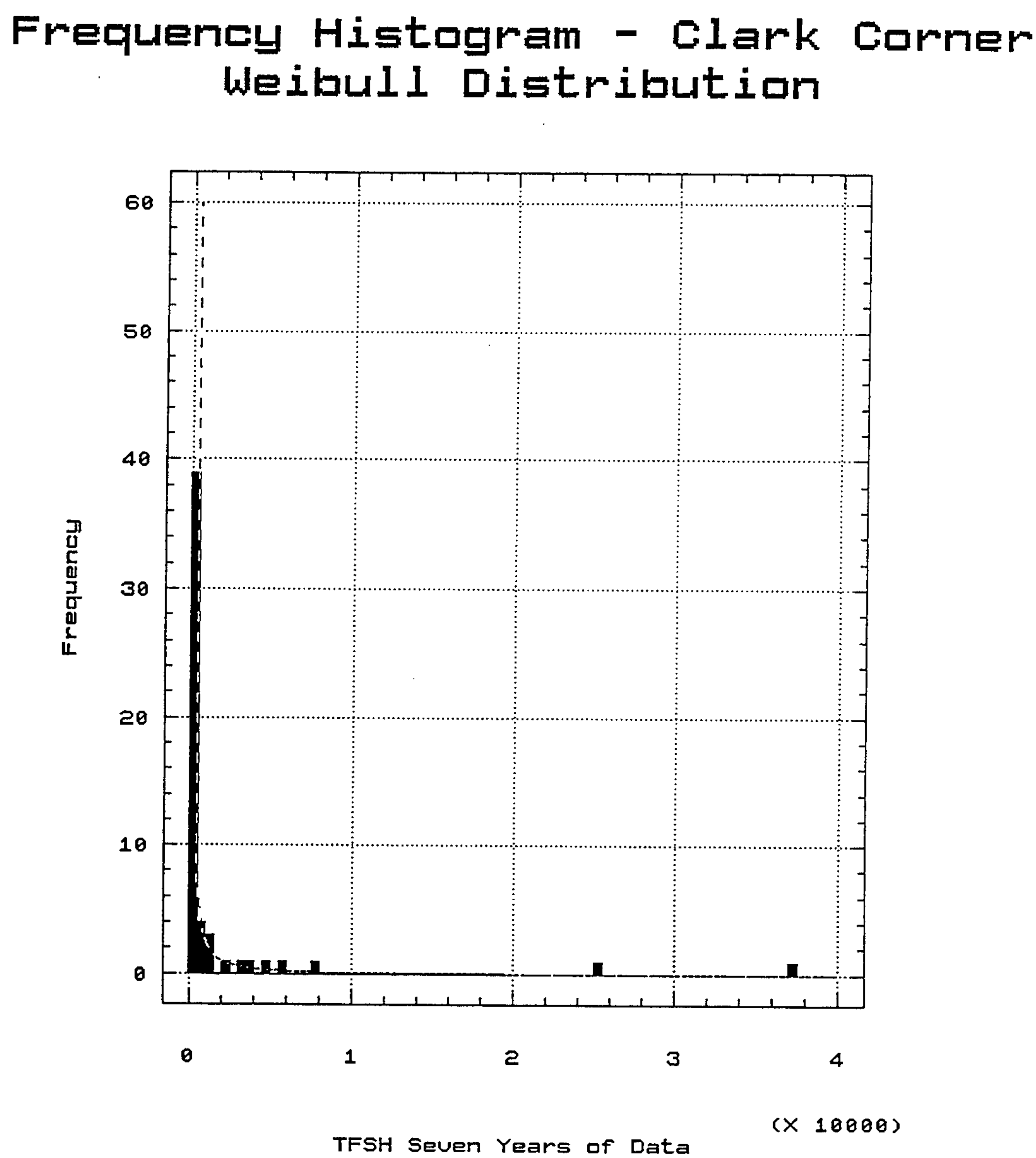

Figure 52. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for seven years of data, Clark Corner, AR

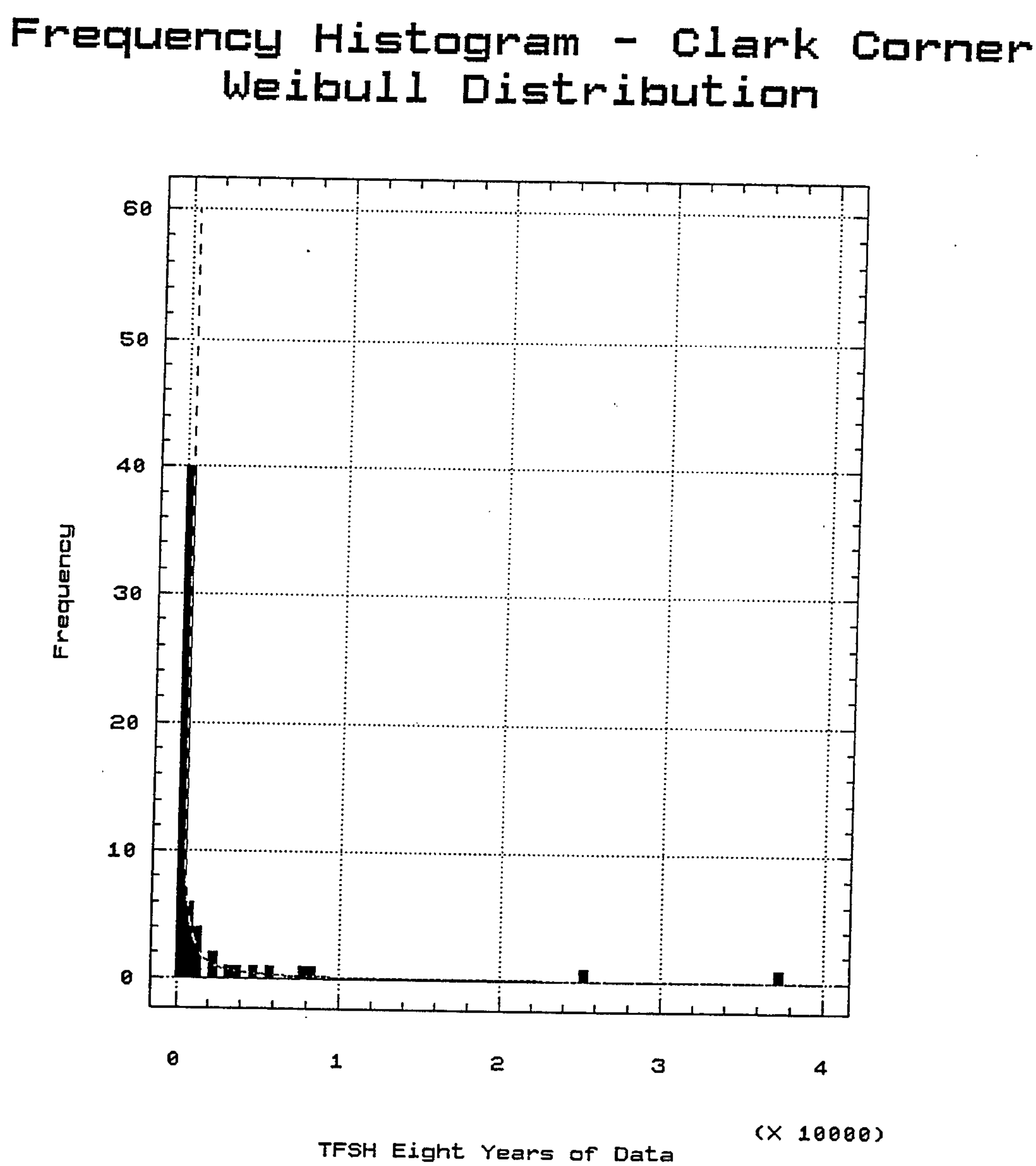

Figure 53. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for eight years of data, Clark Corner, AR

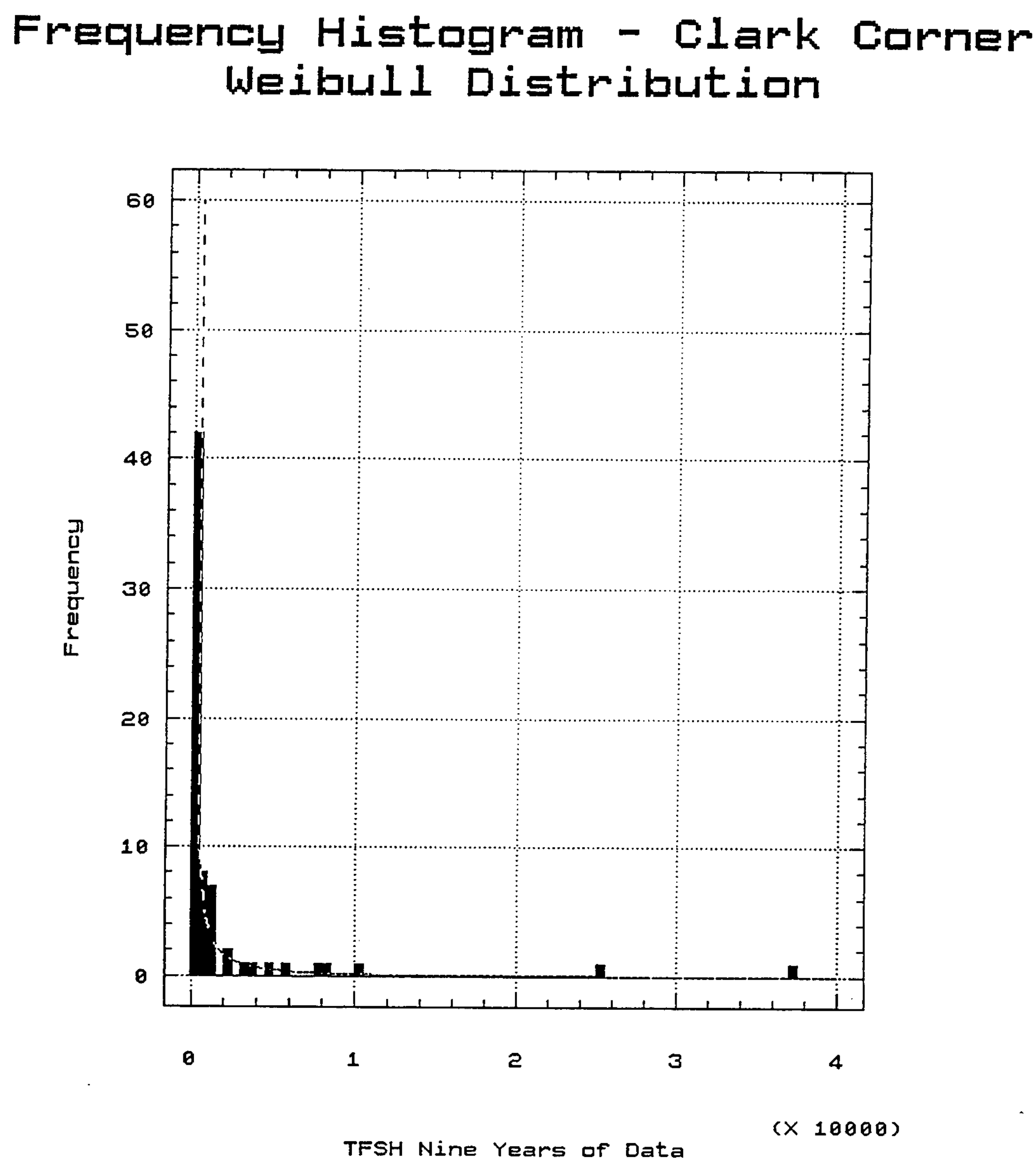

Figure 54. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for nine years of data, Clark Corner, AR

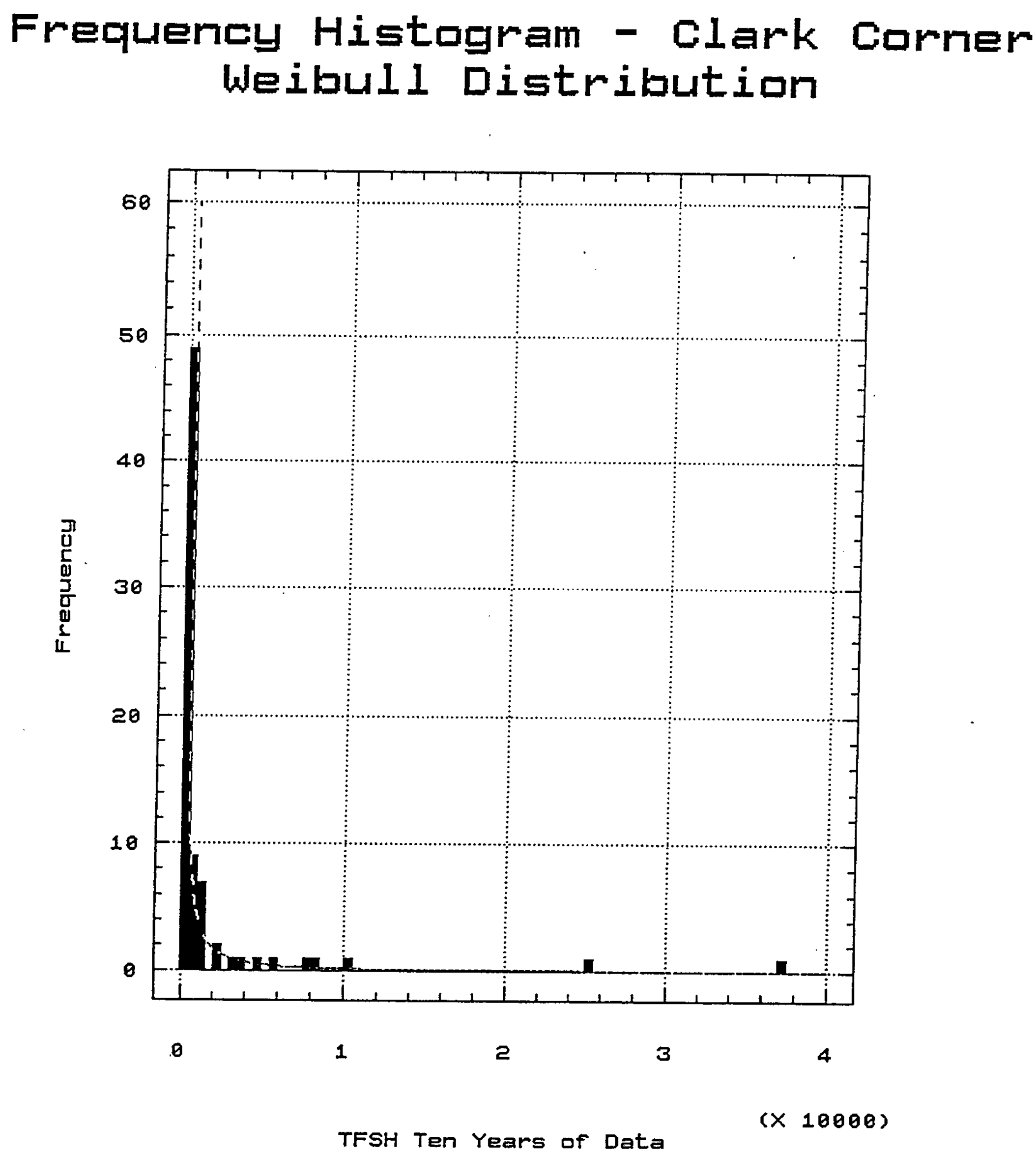

Figure 55. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for ten years of data, Clark Corner, AR

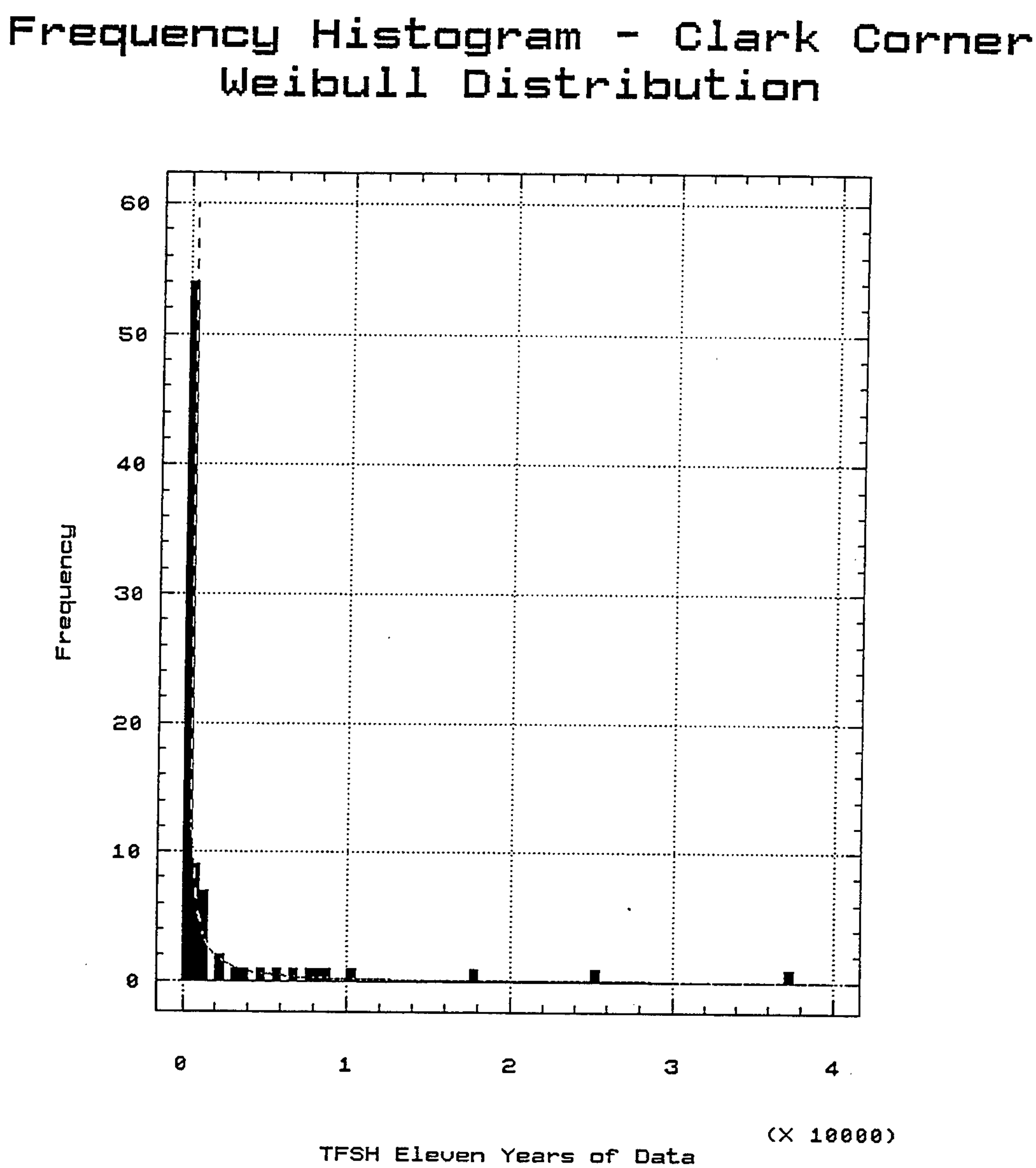

Figure 56. Toffaleti-Schoklitsch transport function results fitted to the Weibull distribution for eleven years of data, Clark Corner, AR

Table 15
Calculated Entropy for Each Station, by Years of Data (40 Intervals for Fisk, 30 Intervals for Wilhelmina and 45 Intervals for Clark Corner)

Number of Years of Data	FISK, MO	WILHELMINA	CLARK CORNER
1	0.6	1	0.5
2	1.04	1.27	0.83
3	1.11	1.3	0.72
4	1.17	1.28	0.56
5	1.32	1.28	0.56
6	1.48	1.5	0.75
7	1.55	1.58	0.99
8	1.77	1.74	1.1
9	1.86	1.74	1.18
10	1.82	1.7	1.09
11	1.83	1.7	1.15

Table 16
Calculated Entropy for Each Station, by Years of Data (40 Intervals for Fisk, 52 Intervals for Wilhelmina and 76 Intervals for Clark Corner)

Number of Years of Data	FISK, MO	WILHELMINA	CLARK CORNER
1	0.6	1.3	0.5
2	1.04	1.89	0.84
3	1.11	1.79	0.72
4	1.17	1.75	0.56
5	1.32	1.81	0.64
6	1.48	1.96	0.94
7	1.55	2.04	1.18
8	1.77	2.2	1.34
9	1.86	2.2	1.45
10	1.82	2.14	1.36
11	1.83	2.15	1.45

The values in Tables 15 and 16 are plotted in Figures 57 and 58, respectively. It should be noted that while the addition of more intervals changed the absolute values of the entropy, the relative relationships were the same. The absolute values have no meaning except as compared to themselves, since the number of intervals can affect the absolute values. It is the pattern of increase that is important, and not the values themselves.

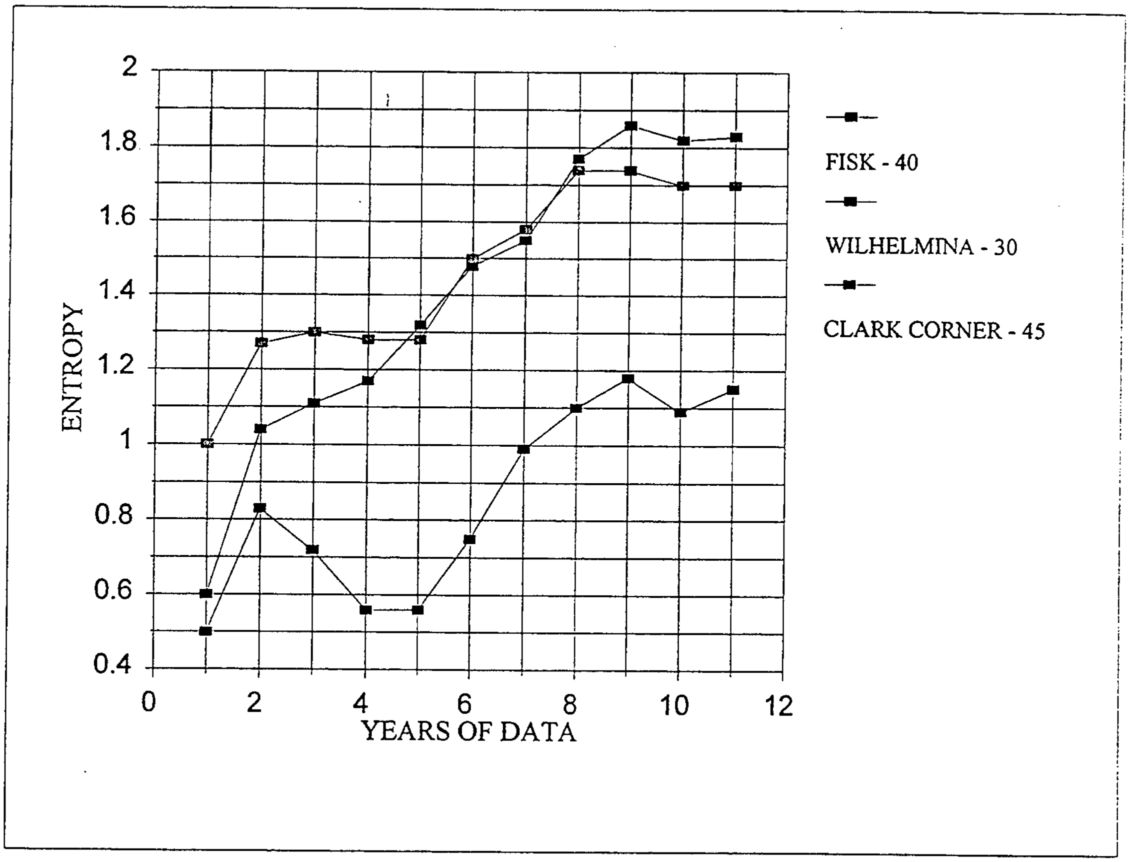

Figure 57. Years of data vs. incremental entropy (40 intervals, Fisk, 30 intervals, Wilhelmina, 45 intervals, Clark Corner, used for entropy computations)

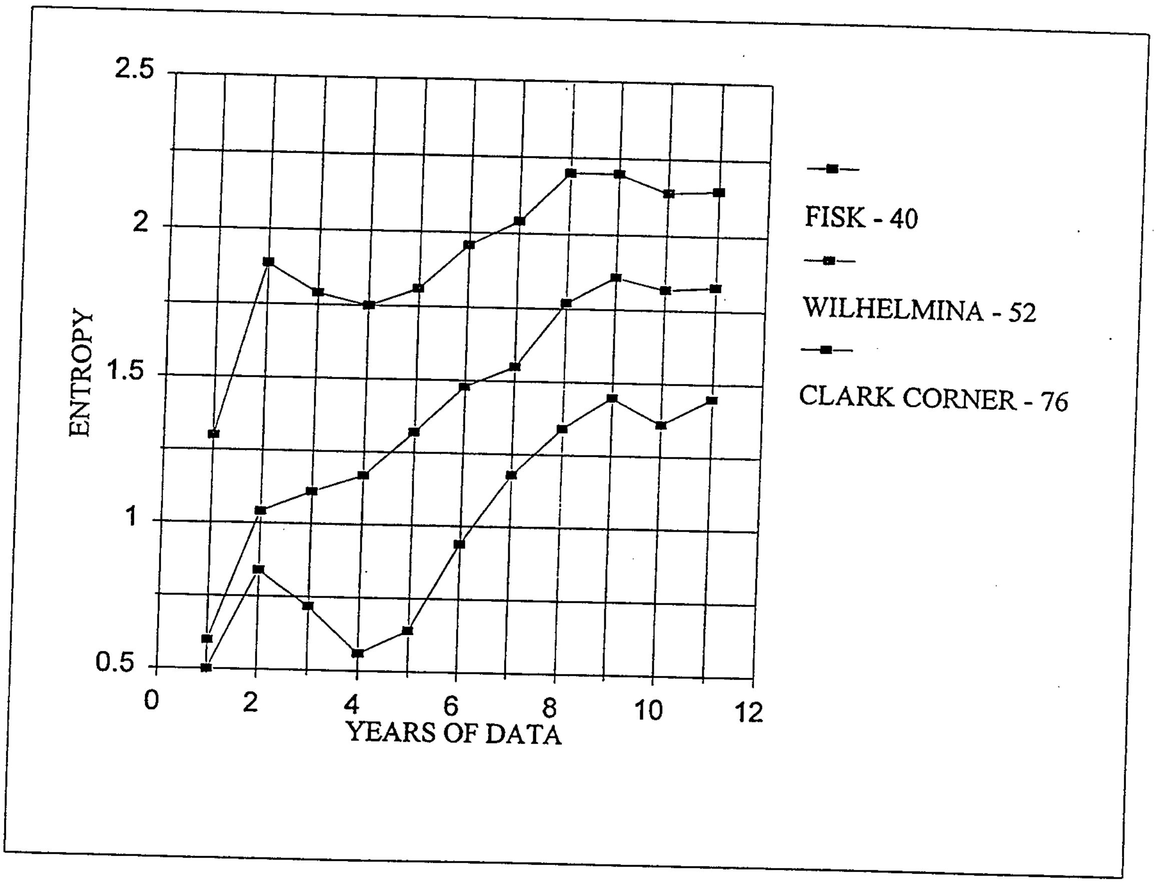

Figure 58. Years of data vs. incremental entropy (40 intervals, Fisk, 52 intervals, Wilhelmina, 76 intervals, Clark Corner, used for entropy computations)

It can be observed in both Figure 57 and Figure 58 that the values of the entropy at the three stations varies with time. However, after eight years at Wilhelmina and nine years at the other two stations, the value of the entropy reaches a maximum. This indicates that the additional data beyond this point of maximum entropy is not decreasing the bias associated with the random variable, sediment transport, nor is any additional information being provided. It has been stated that entropy can be employed as a measure of the degree of ignorance as to the true state of a system (Singh and Fiorentino, 1992). Given this, the additional sediment data beyond year eight (or nine) was again, not adding to the definition of the true values of the state variable, computed sediment transport.

There are also two points worth noting as pertain to the entropy change over time. The drops in entropy noted in years three and four at Wilhelmina and Clark Corner indicate that there is no additional data being transferred by the data during this period at these stations. In addition, the drops in entropy values are likely an artifact of the discretized distribution function, which can only approximate the continuous function. The same conclusions may be drawn from the slight fluctuations in entropy values after the maximum is reached. These are again reflections of the descritized data. The information contained in the data set should and cannot, in reality, drop with the addition of additional data. It can and will, however, reach a point where additional data supplies no more information. These are the maximum values noted above for each station.

Sensitivity Analysis

Having developed a procedure to determine the optimum length of data collection in the St. Francis basin based on historical conditions, a sensitivity analysis was performed to evaluate the order in which the data were presented. To do this, the entropy analysis was repeated for two separate conditions. In one case, the order in which the data were introduced was reversed. That is, the historic year one was introduced as data segment 11. Historic year 11 was introduced as data segment one, and so forth. This was performed for all three stations and the results (maximums boldface) are shown in Table 17.

Table 17
Calculated Entropy for Each Station, by Years of Data, with the Historic Order of Occurrence Reversed (40 Intervals for Fisk, 52 Intervals for Wilhelmina and 76 Intervals for Clark Corner)

Number of Years of Data	FISK, MO	WILHELMINA	CLARK CORNER
1	1.21	1.32	1.07
2	1.36	1.3	0.91
3	1.77	1.63	1.36
4	2.09	2.07	1.59
5	2.07	2.14	1.69
6	**2.1**	**2.23**	**1.72**
7	2.1	2.18	1.69
8	2	2.17	1.54
9	1.91	2.1	1.41
10	1.9	2.19	1.45
11	1.83	2.15	1.45

It can be seen that reversing the historical order of occurrence of the data changed the point of maximum entropy. In each case, the maximum occurred after six years of data were introduced. While different from the results of the historical data analysis, the results were consistent. Based on this portion of the sensitivity analysis, it appears that the approach is still valid. One would expect different results with different data sets. The results are, however, consistent within the basin. They reflect a real pattern of events (if reversed) that might occur. Hydrologic conditions are marked by cycles of drought, flood and "normal" conditions. Therefore, this reversed data still represent a possible sequence of events. The procedure would still determine the optimum length of record to present the maximum amount of information, in this case six years.

Finally, the data were introduced in a totally random fashion. The data sets generated in this manner bore no resemblance to one another from one station to the next. In this case, the resulting sediment transport was not generated by real global and regional weather patterns occurring over the basin, but rather as disjointed and random events. Results derived from this action would not be expected to be uniform for the three stations. Results are shown in Table 18.

In this hypothetical world, the results are different from the previous two cases. It cannot be determined if the values at Fisk and Clark Corner have reached their maximum value. It appears from the rate of increase in their entropy values that these station are at or near the maximum, but more data would be necessary to confirm this. At Wilhelmina, the maximum was reached after the sixth data segment was introduced. Data introduced in this fashion is of interest only from a theoretical standpoint. In reality, the data at the

Table 18
Calculated Entropy for Each Station, by Years of Data, with the Historic Order of Occurrence Introduced Randomly for Each Station. (40 Intervals for Fisk, 52 Intervals for Wilhelmina and 76 Intervals for Clark Corner)

Number of Years of Data	FISK, MO	WILHELMINA	CLARK CORNER
1	0.9	0.9	0.64
2	0.93	1.28	0.52
3	1.09	1.51	0.85
4	1.26	1.8	0.78
5	1.22	1.9	0.82
6	1.33	**2.16**	1.13
7	1.6	2.12	0.99
8	1.65	2.13	1.18
9	1.7	2.06	1.31
10	1.79	2.12	1.42
11	**1.83**	2.15	**1.45**

three station would be somewhat inter-dependent in that the hydrology, temperatures and weather conditions would be similar for each station in a given year. This random approach nullifies that relationship. In spite of this, there are no spurious results that would invalidate the procedure.

Having determined that the procedure can indeed identify the length of record necessary to provide the maximum amount of information at the three stations, it next seemed prudent to determine the impacts of collecting less than the optimal amount of data. For example, suppose that, based on the research herein using the historical data, one might believe that eight or nine years or data were necessary at any point in the St. Francis basin. However, suppose that due to time and/or economic constraints, that one had only five years available to collect data at another point within the basin. What would be the impact? To answer this question, the maximum entropy values were used as a base value. Next, the incremental entropy was divided by this base value. This yields the amount of the total information present at the end of each data segment. These values are presented as a percent in Table 19 for the 40 segment Fisk analysis, the 52 segment Wilhelmina analysis and the 76 segment Clark Corner Analysis. Since information cannot increase beyond the point of maximum entropy, calculations beyond this point would be meaningless and these are not provided. These data are shown graphically in Figure 59.

Table 19
Quantity of Information Supplied by Station with Increasing Size of the Data Set, as a Percent of the Total

Years of Data	Fisk	Wilhelmina	Clark Corner
1	32	59	34
2	56	85	58
3	60	85*	58*
4	63	85*	58*
5	71	85*	58*
6	80	89	64
7	83	93	81
8	95	100	92
9	100	–	100
10	–	–	–
11	–	–	–

* Note, actual amount of information cannot decrease, as calculations would seem to indicate.

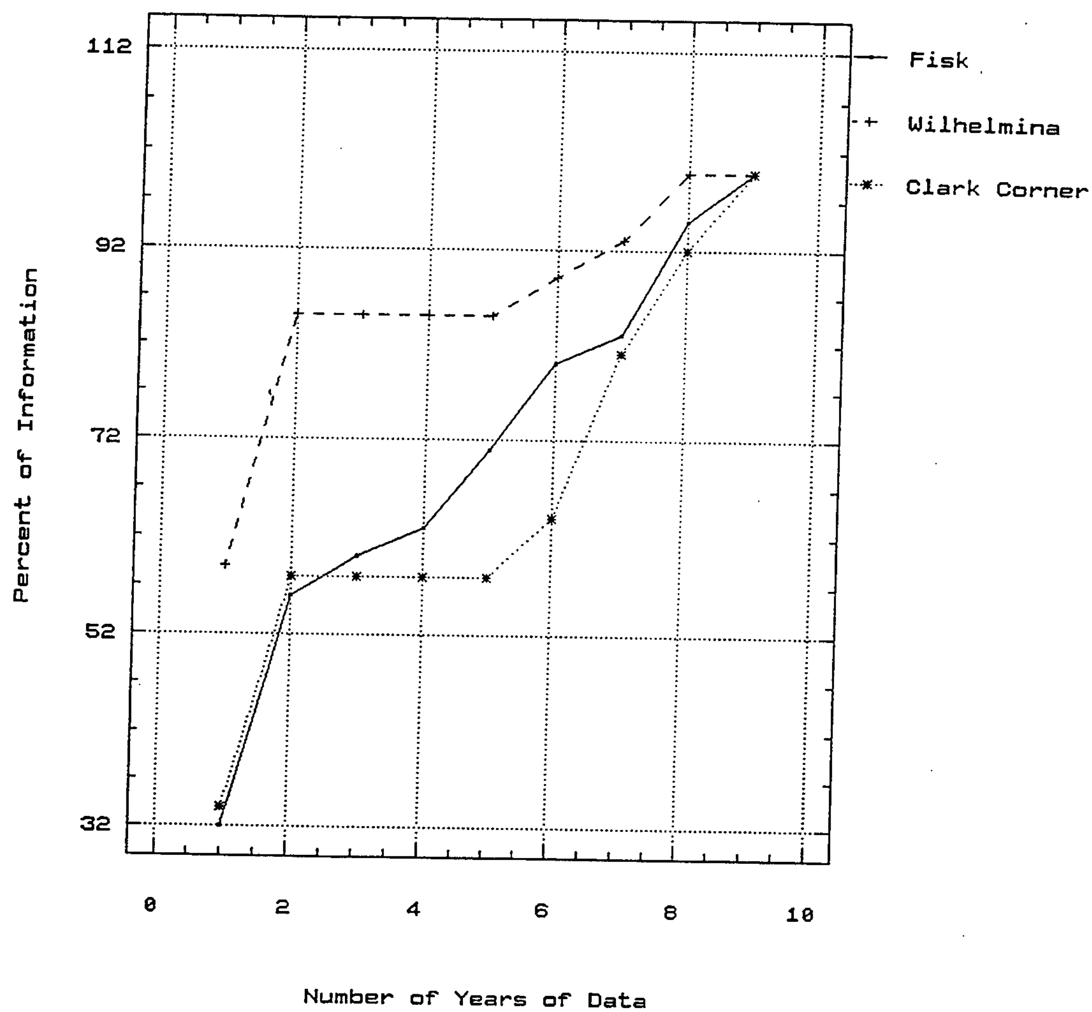

Figure 59. Percent of information gained as more data are added

The results of this calculation show that if only five years of data could be collected, these data would provide between 58 and 71 percent of the maximum information one would get by collecting the recommended amount of data. Using these data and the regression techniques above, one would select the Yang-HEC6 transport function at Fisk, the same decision reached with the full information as shown in Table 10. At Wilhelmina, the Brownlie transport function would be selected based on the five years of data, also the same decision reached with the full information (see Table 12). However, at Clark Corner, one would select the Ackers-White HEC6 transport function, and with some confidence. It is, after all, ranked number one at the end of years 2-5. However, once one has the full information, the Ackers-White function slips to 10th and the best selection is the Toffaleti-Schoklitsch transport function, which was ranked 3rd after year five (see Table 14). It should also be noted that after year five, 71 and 85 percent of the maximum information is available at Fisk and Wilhelmina, while only 58 percent is available at Clark Corner. Therefore, at the stations with a high degree of information available, the correct decision would be made. At Clark Corner, with barely half of the information available, an abysmal decision would be made that looked good based on other commonly used selection criteria. This analysis would suggest that for new stations near Fisk and Wilhelmina, 5 years of record would be sufficient, though not optimum. New stations in the vicinity of Clark Corner require at least eight years of record to insure enough information is available to make the correct decision as to which transport function to use. In any case, the new station data should be checked with the procedure presented in the next chapter to determine the proper length of the data collection effort.

5 A Procedure for Evaluating the Adequacy of Sediment Data Sets

The Procedure

The following procedure is to be used for existing sediment data collection stations. The initial step is to select candidate sediment transport functions for use in the analysis. In this dissertation, ten separate functions were used for research purposes. In practical application, two or three can be selected based on their applicability to the stream to be analyzed. These selection criteria for the transport functions are available from several sources (Vanoni, 1975; Thomas et al., 1992). Once this selection has been made, the data may require augmentation by computing water surface slopes or compiling grain size distribution data information. The sediment computations can then be made. These computations will compute sediment transport for each observation based on hydraulic and sediment parameters measured during the observation. Computer packages such as the U. S. Army Corps of Engineers SAM (Thomas et al., 1992) software greatly ease these computations.

The sediment computations should be conduced in segments. The first segment will contain only one year of hydraulic and sediment data with which to make calculations. Each successive segment will add an additional year of data, so that segment two includes data from years one and two, segment three data from years one, two and three and so forth. A regression analysis may then be performed between the computed and observed sediment discharge. The transport function's performance can be ranked for each segment by comparing the coefficients of determination. The rank of these coefficients can then be plotted versus time. The point at which the values of relative rank cease to change will identify an initial range of minimum data necessary to allow meaningful sediment transport computations to be made. Should no pattern develop and the rank continue to change until all data are added, then sufficient data are not available to define the sediment transport relationship at that station, or different transport functions should be selected and the process repeated.

Next, the computed values should be fitted to a distribution function and the total entropy calculated for the data with succeeding years of data incrementally introduced. If the entropy ceases to increase at some point and remains the same thereafter, then that point defines the amount of data necessary to define the sediment transport relationship. Slight fluctuations in the value after this point are to be expected as artifacts of the discretized distribution function. If no such point is reached, then insufficient data have been collected and the data collection program should continue. If this point lies beyond the point suggested by the regression analysis, then the entropy driven point should take precedence.

Once such a point has been reached, the percentage of information present after addition of each segment of data can be computed based on a percentage of the maximum entropy value. From this, inferences can be made for other locations within the basin where, perhaps, less data are available as to what percent of the information is provided by a data set of less than optimum length.

It occurs to the author that there are conditions under which one may wish to continue data collection even if the procedure outlined above indicates it is no longer necessary. If conditions are expected or could occur which would significantly change the distribution of the data, then one would want to continue the data collection. This would be necessary because a significant change in the distribution could increase the entropy. One such instance would be if significant widespread changes in land use are anticipated. This could affect the sediment water-sediment discharge relationships and alter the distribution of previously collected data. Additional data would add information about the sediment relationships, in this case. Other likely causes would be significant water diversions, dam construction or removal, or natural disasters such as volcanic activity.

The research described herein was conducted at several sites within the St. Francis River basin that were selected to reflect rather different conditions. It was believed that these varied sufficiently so as to essentially be entirely different in nature. The Fisk, Mo., Station is located just below Wappapello dam in a rather stable section of the river, with an average drop in channel grade of one foot per mile, higher than that found in the lower reaches. The bed material samples also varied significantly at this station, resulting in the very low coefficients of determination as shown in Table 6. The Wilhelmina station is located in a highly unstable man-made reach of the river which requires channel clean out periodically to restore the hydraulic conductivity. Slopes are relatively high here, averaging 5.08 feet of drop per mile of channel, as the cutoff reduced the natural channel length by 7 miles. This reach experiences continuous shoaling and displays a high sediment transport load. Even though this was a very active reach for sediment transport, the coefficients of determination were higher than those computed for Fisk, as shown in Table 7. The Clark Corner station is located in another man-made reach but is far more stable. This reach has relatively mild slopes, averaging 0.63 feet per mile, and is just above the section of the river that experiences backwater effects from high Mississippi river stages (USACE, 1992). Thus, the procedure described above was developed under rather different regimes and should be robust enough to account for changing conditions within parameters normally observed in most agricultural basins.

6 Summary and Conclusions

One of the main purposes for collecting sediment data is to provide sufficient data to select a transport function that best represents the observed data. This allows one to make predictions as to future conditions, analyze flows that are different from or outside of the observed data set, and evaluate system responses to proposed changes in the system. These changes may be man induced such as land use changes, structures placed in the channel or other forms of channel modification. The changes may also be due to natural causes, though unless the natural occurrence is of a violent nature, such as an earthquake, volcanic action or forest fire, the time scale is usually too long to be of significance for engineering purposes. The procedure presented in the previous chapter will allow the sediment engineer to assess existing data sets and determine if they adequately describe the sediment transport characteristics of the stream. If not, inferences can be made based on the degree of change in the ranking of the transport functions and the rate of change of the entropy as to how well the data describe the system.

It is common practice to compare observed sediment data with several transport functions and use the one that best matches the data (Julien, 1995). Various methods have been used in the past. Visual comparison of the computed versus the measured sediment discharge was used by Vanoni et al. (1961). This can be demonstrated by looking at the plots in Figures 6-11. The drawbacks to this approach are obvious. While the transport functions that match neither the trend or the vales are obvious, it is difficult to distinguish between those that cluster near the observed data. Other researchers (White et al., 1973; Yang and Wan, 1991) have applied the discrepancy ratio (the ratio of the observed to the calculated values) as a measure of which transport function best matches the observed data. Since the ratios are almost never "one", it is difficult to interpret the differences, which are numbers such as 3.6 or 0.45, at a glance. A different approach has been proposed by Gomez and Church (1989). This method uses the analysis of variance (ANOVA) method to compare local bias and mean bias values between the computed and observed sediment transport. However, this method also displays results as a distribution of the ratio of the computed values to those of the observed. Again, the results require some detailed analysis to interpret.

The regression method used in this dissertation to rank the sediment transport functions and select the best one is unique. While regression methods have been applied previously by other researchers, they have never been applied incrementally to segments of the data set. This method requires that a transport function be the best ranked incrementally over the data set. Furthermore, this method specifies that a transport function also be the best performer coincidentally with the maximum amount of information. The incremental analysis points out the dangers involved with selecting a transport function based on a finite set of data, especially if the data set is not providing the maximum amount of information. The results of this procedure are easy to interpret, either from tables or graphically.

The regression method applied herein was first performed with the full data set for each station. Based on the analyses at the three stations, a different transport function best matched the observed data at each station. Furthermore, each of the number one ranked equations had a different theoretical basis. At Fisk, MO, the Yang-HEC6 transport function was the highest ranked. It is based on stream power and has been modified by the WES to calculate sediment transport by size class. At Wilhelmina, Mo., the Brownlie Function best matched the observed data. This function is an empirical formulation based on regression analysis. At Clark Corner, AR, the hybrid Toffaleti-Schoklitsch function best matched the observed data. This formula calculates the sediment transport using both the methods of Toffaleti and those of Schoklitsch and uses the higher value. This hybrid function only marginally outperformed the basic Toffaleti function at this station, as indicated by comparing the coefficients of determination. The value based on the full data set for the hybrid was 78.46 versus 78.44 for the basic function. This indicates little was gained by adding the bed load computations. This function is based on the advection-diffusion approach of Einstein. The Schoklitsch function is an empirical formula that is primarily recommended for bed load computations. Having noted the variation of functions and their theoretical bases, overall the Brownlie function was the best performer. It ranked 3, 1 and 3 at Fisk, Wilhelmina and Clark Corner respectively. The Toffaleti-Schoklistch function ranked 2, 6 and 1 and the Yang-HEC6 function ranked 1, 4 and 4 respectively. Brownlie's average finish was

2.33 compared to 3.0 for both Yang-HEC6 and Toffaleti-Schoklistch. All three of these were excellent performers. This was not unexpected given that they quite often finish very high when compared to other transport functions using actual river data (Yang and Molinas, 1991; Brownlie, 1981).

It has been shown that reliance totally on regression methods, if the data record is of insufficient length, may lead to selection of the incorrect transport function and/or validate too short a sampling period. For example, based solely on regression analysis, for the stations analyzed in this report, one might look at one year of data and select the Colby-HEC6 transport function for Fisk, Mo. However, based on the full eleven years of record, the Colby-HEC6 function finished seventh out of ten at Fisk. If one looked at four years of record at Fisk, one would select the Yang-HEC6 transport function. Indeed, this is the number one rated function even after eleven years of data have been collected. However, looking at the entropy analysis reveals that four years provide only 63 percent of the information available after nine years at Fisk. Use of relative rank of the transport functions as determined by regression analysis is at best good for determining a broad range of values within which the true minimum record length resides. The regression methods presented herein are good, however, for determining the transport function that best fits the observed data. Simply looking at the base data from which the functions were developed can lead to very erroneous selections. For instance, based on the average size of the bed sediment and sand bed nature of the St. Francis River, the Ackers-White transport function would be expected to be a good predictor. To the contrary, the single grain size function ranked overall 10, 9, and 10 at Fisk, Wilhelmina and Clark Corner respectively. The multiple grain size version did only marginally better with ranks of 4, 10, and 9 overall. As discussed earlier, this was undoubtedly due to variations in the bed material. The Colby-HEC6 function was also a poor performer. This function ranked 7, 2, and 8, respectively, at Fisk, Wilhelmina and Clark Corner. This function was developed from flume data and most values in the 10 foot depth and all in the 100 foot depth range were extrapolated from flume data. Therefore, this function may not be the best for larger natural streams that may often have flow depths greater than 10 feet, including the St. Francis River. The incremental regression method shows which functions are the best performers over a broad range of data.

The change in order of ranking of the transport equations as data are added seems to have some significance. Using incremental analysis of the data, if the order of ranking of the transport functions are similar, with only a small change in order toward the end of the data set, then the data would seem to be nearly adequate. If, on top of these conditions, the rate of change in entropy is very small or zero, then additional proof is offered that the data set is adequate. The critical conditions for selection of the best transport equation are;

1. The range of key variables, such as velocity, depth and bed sediment size, are within the range recommended for the transport function.

2. The top ranked function remains so over several data segments.

3. Relatively stable relative ranking of the best performers over a portion of the data set, particularly as the optimum length of the data set is approached.

4. The optimal length of data collection is determined using entropy principles and the selected transport function should be top ranked at this point.

If, on the other hand, the rank order of the equations is varying wildly or the rate of change in the entropy is not zero, then strong evidence exists that the data set is not sufficient to describe the sediment transport characteristics of the stream.

The principle of entropy has been successfully applied to determine the optimum length of sediment data collection at three stations in the St. Francis river basin. This optimum length was nine years at two stations (Fisk, Clark Corner) and eight years at Wilhelmina, based on the historical data. This is the first definitive guidance developed as to how much data need be collected to provide the most information on sediment transport at a given location. With the historic order of data reversed, the optimum length of data collection was 6 years and was consistent at each station. Analysis of this showed the difference in results were due to the order in which the distribution intervals were filled. After nine years at Fisk, there were 85 observations placed in 17 of 40 intervals. Forty five of these were clustered in the first interval. After 6 years at Fisk, with the order of data reversed, there were 47 observations placed in 13 of 40 intervals. Eighteen of these were in the first interval. Therefore, though the historic record had 38 more observations than the reverse order data set, 27 of these were in the first interval and added little information. A similar pattern was observed at Clark Corner, in the lower end of the basin. After nine years, there were 68 observations placed in 13 of 76 intervals. Forty two of these were clustered in the first interval. After 6 years at Clark Corner, with the order of data reversed, there were 43 observations placed in 12 of

76 intervals. Nineteen of these were in the first interval. Therefore, though the historic record had 25 more observations than the reverse order data set, 23 of these were in the first interval and added little information. Therefore, the procedure is consistent and awards short data sets with better distribution over larger, more poorly distributed data sets.

Therefore, the basic question that has been answered and, indeed, is the topic of this research, is how much data are needed? Historically, the answer has been "as much data as can be afforded within study budget constraints of time and money". Clearly if this method has ever provided adequate data it was serendipity as in most all cases either too little or too much data would be collected. The above outlined procedure (Chapter 5) allows the sediment engineer to evaluate existing data sets as to their adequacy, that is, answer the question "Do I have enough data?". It also allows one to select the best sediment transport equation given the available data, and make a determination as to how well the equation will describe the sediment transport within the stream reach. Predictions and/or evaluations can then be made with some degree of surety as opposed to assuming data available are adequate and that the selected sediment transport equation is the best available. The entropy procedure also provides a quantitative indication as to the amount of information available for the predictive system. The procedure has been proven robust through sensitivity analyses. While randomly introducing the data destroyed the pattern observed between historical data collection stations and the same data introduced in reverse order, it none-the-less was still useful in determining if the maximum amount of information was present. It has also been proven that the distribution of the data is more important than the quantity of data.

Thus, one can use the methods of this report and determine if sufficient data are available. If not, then some notion as to what percent of the maximum information is available can be made. This can be determined by looking at the rate of increase in the entropy. If it is increasing rapidly, then the rate of information addition is high and one additional year of data would be more valuable. If the rate of change is low, then additional data will likely not add much additional information.

The procedure developed herein has application in real world decision making. For example, the original St. Francis river sediment data collection program consisted of 24 stations. This number was reduced in 1983 and again in 1985. These reductions were dictated by economic necessity. In actuality, the decisions were made based on the perceived goodness of the data collected and importance of each station's location. Using the method of this report, a quantitative basis could have been established for removing or, keeping, individual stations. It is possible that in 1985 a number of stations could have been dropped based on the findings at in this report. A case could also have been made to continue sampling, checking yearly, until the optimum length had been reached at individual stations. This could be done in the following manner. If one were to conduct an incremental analysis of information, normalized to a base year taken to be the proceeding year, then the rate and relative value of information added by taking additional data could be determined. For example, let us look at the Wilhelmina station. Using the values from Table 16. The incremental entropy, or information added, can be calculated as

$$\frac{1.89-1.30}{1.30}=.45$$

Continuing this process yields the following results, as shown in Table 20. A case could be made to continue collecting data prior to year 9. After that time, cessation of data collection at this station could be justified. Of course, one may not know the maximum value has been reached until the optimum number of years plus one of data have been collected. This is because to identify the maximum value would require at least one more year of data, as can be inferred from Table 16.

Table 20
Incremental Entropy for Each additional Year of Data, Wilhelmia, Mo.

Incremental Entropy From ___ year To ___ year	Incremental Entropy
1 - 2	0.45
2 - 3	0.00*
3 - 4	0.00*
4 - 5	0.03
5 - 6	.08
6 - 7	.04
7 - 8	.08
8 - 9	0.00**

* Although the calculated values is less than zero, information cannot be deleted by additional sampling. These values are due to the discretized distribution.
** Actual maximum entropy location

The procedure presented herein could also be applied to assist in designing a data collection program. If data were available in a basin and had previously been analyzed using the methods of this dissertation, then one could make an educated estimate of the length of data needed at a new location within the basin. The data collected at the new location could be checked with the incremental method outlined above and some notion provided as to the amount of information gained with each additional year of data collected.

Of course, like any new procedure, this one needs to be applied by other researchers to streams other than the St. Francis River. It has been rather rigorously applied in the St. Francis basin and can be used to evaluate data in this basin. It is recommended that this procedure be applied to a number of streams. In so doing, it is my belief that a body of knowledge can be assembled that will offer insight as to just how much data are required for a given type of stream, be it a medium sized alluvial basin such as the St. Francis River basin, or one with different material types and slope characteristics. Over time, it may come to pass that the length of data for each class of stream can be determined fairly accurately, from climate and basin characteristics much as Manning's "n" values are now determined by a cursory inspection of a channel reach. However, it should be noted that due to sensitivity of the procedure to the order in which the data are added, that the author would not recommend directly transferring results from one basin to another until further research has been done on the performance of the procedure on similar but geographically separated basins.

In addition to the above procedures, the author has, in pursuit of this research, assembled a truly unique set of sediment data. These data, much of which are unpublished elsewhere, are an extremely valuable asset. They can serve as a basis to further the research described herein, or to provide other researchers with an invaluable data source to further the knowledge of sediment transport. Hopefully, the use of this data may refine existing methods and procedures and/or lead to new findings which further the field of Sedimentation Engineering.

REFERENCES

References

Ackers, P. and White, W. R. (1973). "Sediment transport: new approach and analysis," *Journal of the Hydraulics Division* 1, 2041-2059.

Amorocho, J. and Espildora, B. (1973). "Entropy in the assessment of uncertainty in hydrologic systems and models," *Water Resources Research* 9(6), 1551-1522.

Amumah, K., Goulter, I., and Bhatt, S. K. (1991). "Entropy-based distribution measures in water-distribution networks," *Journal of Hydraulic Engineering* 117(5), 595-614.

Arora, K. and Singh, V. P. (1987a). "On statistical intercomparison of EV1 estimators by monte carlo simulation," *Advances in Water Resources* 10(2), 87-107.

Arora, K. and Singh, V. P. (1987b). "An evaluation of seven methods for estimating parameters of the EV1 distribution." *Hydrologic Frequency Modeling.* V.P. Singh, ed., D. Reidel Publishing, Boston, MA, 383-394.

Arora, K. and Singh, V. P. (1989). "A comparative evaluation of the estimates of log-pearson type (LP) 3 distribution," *Journal of Hydrology* 105, 19-37.

Boltzman, L. (1872). "Weitere studien uber das warmegleichgewich unter gasmolekulen," K. Acad. Wiss (Wein) Sitzb., II Abt., Vol 66, pp 275.

Borland, Intl. (1990). "Quattro Pro", (computer program), IBM PC, Scotts Valley, CA.

Brownlie, W. R. (1981). "Prediction of flow depth and sediment discharge in open channels," Report No. KH-R-43A, California Institute of Technology, Pasadena, CA.

Chapman, T. G. (1986). "Entropy as a measure of uncertainty," *Journal of Hydrology* 85, 111-126.

Chiu, C. L. (1986). “Entropy and probability concepts in hydraulics,” *Journal of Hydraulic Engineering* 113(5), 583-600.

Chiu, C. L. (1988). “Entropy and 2-D velocity distribution in open channels,” *Journal of Hydraulic Engineering* 114(7), 738-756.

Chow, V. T. (1959). *Open-Channel Hydraulics.* McGraw-Hill Book Company, New York, NY.

Copeland, R. R. and Thomas, W. A. (1989). "Corte Madera creek sedimentation study," Technical Report HL-89-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Colby, B. R. (1964). "Practical computation of the bed material discharge," *Journal of the Hydraulics Division* 2, 217-246.

Computer Associates. (1987). “Supercalc4" (computer program), IBM PC, San Jose, CA.

Duboys, M. P. (1879). “Le Rohne et les rivieres a lit affouillable,” Annales des Ponts et Chaussees, Series 5, 18, 145-195.

Einstein, H. A. (1942). “Formulas for the transportation of bed load.” *Transactions.* American Society of Civil Engineers 107, 561-573.

Einstein, H. A. (1950). “The bedload function for sediment transport in open channel flows,” Technical Bulletin No. 1026, U.S. Department of Agriculture, Soil Conservation, Washington, DC.

Gomez, B. and Church, M. “An assessment of bed load sediment transport formulae for gravel bed rivers,” *WaterResources Research* 25(6), 1161-1186.

Guy, H. P. "Quality control of adjustment coefficients," U.S. Geological Survey Professional Paper 600-B, 165-168.

Guy, H. P. and Norman, V. W. (1970). "Techniques of water resources investigations of the United States Geological Survey; Field Methods for Measurement of Fluvial Sediment, Book 3, Chapter C2," U.S. Geological Survey, Washington, DC.

Fiorentino, M. Arora, K. and Singh, V. P. (1987a). “On the two-component extreme value distribution and its point and regional estimators.” *Regional Flood Frequency Analysis.* V. P. Singh, ed., D. Reidel Publishing, Boston, MA, 252-272.

Fiorentino, M. Arora, K., and Singh, V. P. (1987b). "The two-component extreme value distribution for flood frequency analysis: another look and derivation of a new estimation method," *Stochastic Hydrology and Hydraulics* 1, 199-208.

Harmancioglu, N. B. (1981). "Measuring the information content of hydrologic processes by the entropy concept," *Journal of the Civil Engineering* Centenial of Ataturk's Birth, 13-38.

Harmancioglu, N. B. (1984). "Entropy concept as used in determination of optimal sampling intervals," *Proceedings of the international conference on hydraulic engineering software,* HYDROSOFT '84, Potoroz, Yugoslavia, 6-110.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1940). "Field practice and equipment used in sampling suspended sediment," Report 1, St. Paul Engineer District Sub-Office Hydraulic Laboratory, Iowa City, Iowa.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1940). "Equipment used for sampling bed load and bed material," Report 2, St. Paul Engineer District Sub-Office Hydraulic Laboratory, Iowa City, Iowa.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1941). "Analytical study of methods of sampling suspended sediment," Report 3, St. Paul Engineer District Sub-Office Hydraulic Laboratory, Iowa City, Iowa.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1941). "Methods of analyzing sediment samples," Report 4, St. Paul Engineer District Sub-Office Hydraulic Laboratory, Iowa City, Iowa.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1941). "Laboratory investigations of suspended-sediment samplers," Report 5, St. Paul Engineer District Sub-Office Hydraulic Laboratory, Iowa City, Iowa.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1952). "The design of improved types of suspended-sediment samplers," Report 6, St. Anthony Falls Hydraulic Laboratory, Minneapolis, MN.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1943). "A study of new methods for size analysis of suspended-sediment samples," Report 7, St. Paul Engineer District Sub-Office Hydraulic Laboratory, Iowa City, Iowa.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1948). "Measurement of the sediment discharge of streams," Report 8, St. Paul Engineer District Sub-Office Hydraulic Laboratory, Iowa City, Iowa.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1953). "Accuracy of sediment size analyses made by the bottom-withdrawl tube method," Report 10, St. Anthony Falls Hydraulic Laboratory, Minneapolis, MN.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1957). "The development and calibration of the visual-accumulation tube," Report 11, St. Anthony Falls Hydraulic Laboratory, Minneapolis, MN.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1957). "Some fundamentals of particle size analysis," Report 12, St. Anthony Falls Hydraulic Laboratory, Minneapolis, MN.

Interagency Committee on Water Resources, Subcommittee on Sedimentation. (1961). "The single-stage sampler for suspended sediment," Report 13, St. Anthony Falls Hydraulic Laboratory, Minneapolis, MN.

Jain, D. and Singh, V. P. (1986). "Estimating parameters of EV1 distribution for flood frequency analysis," *Water Resources Bulletin* 23(1), 59-72.

Jaynes, E. T. (1957a). "Informational theory and statistical mechanics I," Physical Review, 106, 620-630.

Jaynes, E. T. (1957b). "Informational theory and statistical mechanics II," Physical Review, 108, 171-190.

Jones, H. Wayne (1977). "Manual for a conversationally oriented real-time program-generating system (CORPS)," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Jowitt, P. W. (1979). "The extreme-value type I distribution and the principle of maximum entropy," *Journal of Hydrology* 42, 23-28.

Jowitt, P. W. (1991). "A maximum entropy view of probability-distributed catchment models," *Hydrologic Sciences Journal* 36(2/4), 123-134.

Julien, P. Y. (1995). *Erosion and sedimentation,* 1st ed., Cambridge University Press, New York.

Krstanovic, P. F. and Singh, V. P. (1988a). "Application of entropy theory to multivariate hydrologic analysis," Vol. 2, Technical Report WRR9, Water Resources Program, Department of Civil Engineering, Louisiana State University, Baton Rouge, LA.

Krstanovic, P. F. and Singh, V. P. (1988b). "Application of entropy theory to multivariate hydrologic analysis," Vol. 1, Technical Report WRR9, Water Resources Program, Department of Civil Engineering, Louisiana State University, Baton Rouge, LA.

Lane, E. W. (1947). "Report of the subcommittee on sediment technology," *Transactions*, American Geophysical Union 28(6), 936-938.

Leopold, L. B. and Langbein, W. B. (1962). "The concept of entropy in landscape evolution," Geological Survey Professional Paper 500-A, Geological Survey, Washington, DC.

Madden, E. B. (1985). "Modified Laursen method for estimating bed-material sediment transport," prepared for the U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Manugistics, Inc. (1993). "Statgraphics" (computer program), IBM PC, Rockville, MD.

Martin, W. D. (1988). "Martins Fork Lake sedimentation study," Technical Report HL-88-21, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Meyer-Peter, E. and Muller, R. (1948). "Formulas for bed-load transport," *Proceedings, International Association for Hydraulic Research,* Stockholm, Sweden, Appendix 2, 39-5.

Porterfield, G. (1972). "Techniques of water resources investigations of the United States Geological Survey, computation of fluvial sediment discharge, Book 3, Chapter 3," U.S. Geological Survey, Washington, DC.

Prasuhn, A. L, Lewandoski, A. M., and Bagherzadeh, M. H. (1987). "Ackers-White equation: transportation by size fractions," *Proceedings of the 1987 National Conference on Hydraulic Engineering,* R. M. Ragan, ed., American Society of Civil Engineers, New York.

SAS Institute, Inc. (1988). "SAS System," (computer program), IBM PC, Cary, NC.

Shannon, C. E. (1948a). "The mathematical theory of communications, I and II," Bell System Technical Journal 27, 379-423.

Shannon, C. E. (1948b). "The mathematical theory of communications, III and IV," Bell System Technical Journal 27, 623-656.

Shen, H. W. (1971). "Instrumentation and measuring techniques," *River Mechanics, Vol I.* H. W. Shen, Fort Collins, CO.

Shen, H. W., Hikkawa. (1980). *Application of stochastic processes in sediment transport.* Water Resources Publications, Littleton, CO.

Shultis, S. (1935). "The Schoklitsch bed-load formula," *Engineering,* London, England, 644-646.

Singh, V. P and Jain, D. (1985). "Comparing methods of parameter estimation for EV1 distribution for flood frequency distribution." *Proceedings of the Vth World Congress on Water Resources, Vol. 3.* Brussels, Belgium, 1119-1132.

Singh, V. P. and Singh, K. (1985a). "Derivation of the gamma distribution using the principle of maximum entropy (POME)," *Water Resources Bulletin* 21(6), 941-952.

Singh, V. P. and Singh, K. (1985b). "Derivation of the pearson type (PT) III distribution by using the principle of maximum entropy," *Journal of Hydrology* 80, 197-214.

Singh, V. P. and Singh, K. (1985c). "Pearson type III distribution and the principle of maximum entropy." *Proceedings of the Vth World Congress on Water Resources, Vol 3.* Brussels, Belgium, 1133-1146.

Singh, V. P. and Singh, K. (1988). "Parameter estimation forlog-pearson type III distribution by POME," *Journal of Hydraulic Engineering* 114(1), 112-122.

Singh, V. P., Rajagopal, A. K., and Singh, K. (1986). "Derivation of some frequency using the principle of maximum entropy (POME)," *Water Resources Bulletin* 9(2), 91-106.

Singh, V. P., Rajagopal, A. K., and Singh, K. (1987). "A new method of parameter estimation for hydrologic frequency analysis," *Hydrologic Science and Technology* 2(3), 33-40.

Singh, V. P. and Krstanovic, P. F. (1987). "A stochastic model for sediment yield using the principle of maximum entropy," *Water Resources Research* 23(5), 781-793.

Singh, V. P., Cruise, J.F., and Ma, M. (1989). "A comparative evaluation of the estimators of two distributions by monte carlo simulation," Technical Report WRR13, Water Resources Program, Department of Civil Engineering, Louisiana State University, Baton Rouge, LA.

Singh, V. P., Cruise, J. F., and Ma, M. (1990a). “A comparative evaluation of the estimators of the three-parameter lognormal distribution by monte carlo simulation,” *Computational Statistics and Data Analysis* 10, 71-85.

Singh, V. P., Cruise, J. F., and Ma, M. (1990b). “A comparative evaluation of the estimators of the weibull distribution by monte carlo simulation,” *Journal of Statistical Computation and Simulation* 36, 229-241.

Singh, V. P. and Fiorentino, M. (1992). “A historic perspective of entropy applications in water resources,” *Entropy and Energy Dissipation in Water Resources.* V. P. Singh and M. Fiorentino, ed., Kluwer Academic, Netherlands, 21-61.

Sonuga, J. O. (1972). “Principle of maximum entropy in hydrologic frequency analysis,” *Journal of Hydrology* 17(3), 177-219.

Sonuga, J. O. (1976). “Entropy principle applied to the rainfall-runoff process,” *Journal of Hydrology* 30, 81-94.

Thomas, W. A., Copeland, R. R., Raphelt, N. K., and McComas, D. N. (1992). "Hydraulic design package for channels (SAM)," U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Toffaleti, F. B. (1969). "Definitive computations of sand discharge in rivers," *Journal of the Hydraulics Division* 1, 225-248.

Toffaleti, F. B. (1968). "A procedure for computation of the total river sand discharge and detailed distribution, bed to surface," Technical Report No. 5, Committee on Channel Stabilization, U.S. Army Corps of Engineers, Washington, DC.

USACE. (1906). “A plan for improvement of the St. Francis river basin,” U.S. Army Corps of Engineers, Memphis, TN.

USACE. (1948). "A study of methods used in measurement and analysis of sediment loads in streams," U.S. Army Corps of Engineers, St. Paul, MN.

USACE. (1985). “St. Francis river below Wappapello Lake, MO & AR, comprehensive study, Vol 2," U.S. Army Corps of Engineers, Memphis,TN.

USACE. (1992). “Stages and discharges of the Mississippi river and tributaries in the Memphis District”, U.S. Army Corps of Engineers, Memphis,TN.

USGS. (1977). "Water resources data - Arkansas, water year 1977," U.S. Geological Survey Water Data Report 77-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1978). "Water resources data - Arkansas, water year 1978," U.S. Geological Survey Water Data Report 78-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1979). "Water resources data - Arkansas, water year 1979," U.S. Geological Survey Water Data Report 79-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS (1980). "Water resources data - Arkansas, water year 1980," U.S. Geological Survey Water Data Report 80-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1981). "Water resources data - Arkansas, water year 1981," U.S. Geological Survey Water Data Report 81-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1982). "Water resources data - Arkansas, water year 1982," U.S. Geological Survey Water Data Report 82-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1983). "Water resources data - Arkansas, water year 1983," U.S. Geological Survey Water Data Report 83-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1984). "Water resources data - Arkansas, water year 1984," U.S. Geological Survey Water Data Report 84-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1985). "Water resources data - Arkansas, water year 1985," U.S. Geological Survey Water Data Report 85-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1986). "Water resources data - Arkansas, water year 1986," U.S. Geological Survey Water Data Report 86-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

USGS. (1987). "Water resources data - Arkansas, water year 1987," U.S. Geological Survey Water Data Report 87-1, U.S. Department of the Interior, Geological Survey, Little Rock, AR.

Vanoni, V. A., Brooks, N. H., and Kennedy, J. F. (1961). "Lecture notes on sediment transportation and channel stability," Report KH-R-1, W. M. Keck Laboratory of Hydraulics and Water Resources, California Institute of Technology, Pasadena, CA.

Vanoni, V. A. (1975). *Manuals and reports on engineering practice, no. 54, sedimentation engineering.* American Society of Civil Engineers.

White, W. R., Milli, H., and Crabbe, A. D., "Sediment transport: an appraisal of available methods," Report 119, U. K. Hydraulics Res. Stat., Wallingford, England.

Yang, C. T. (1973). "Incipient motion and sediment transport," *Journal of the Hydraulics Division* 10, 1679-1703.

Yang, C. T. (1984). "Unit stream power equation for gravel," *Journal of the Hydraulics Division* 12, 1783-1797.

Yang, C. T. and Wan, S. (1991). "Comparisons of selected bed-material load formulas," *Journal of Hydraulic Engineerin* 117(8), 973-989.

APPENDIX A

SAMPLE COMPUTER INPUT/OUTPUT

SAMPLE SAS OUTPUT

Chronological list of data for Fisk, Wilhelmina and Clark Corner

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 1 7040000 1977 10 19 1210.0  365.0 59.9   33.54 .  41 .  . 100 93.00 86.2 78.00 . . . . . . . . . . . . . . . . . . . . . . . . . . 100  99.0 75.1 25.0 16.0  80  421.0 0.72  8.40  5.26 0.1700 0.25 .0001706
 2 7040000 1977 11 15 1505.0  925.0 52.7  177.32 .  71 . 100 100 94.05 66.0 56.51 . . . . . . . . . . . . . . . . . . . . . . . . . 100  90.0 77.1 44.0 33.1 118  983.0 0.94 11.30  8.33 0.1400 0.17 .0001912
 3 7040000 1977 12 14  745.0 2860.0 37.4 1436.29 . 106 . . . . . . . . 100  52.5 26 21.1 . . . . . . . . . . . . . . . . . . . . 100  96.3 54.5 12.5  8.2 128 1850.0 1.55 20.70 14.65 0.2200 0.28 .0001908
 4 7040000 1978  2 27 1300.0  654.0 39.2   63.57 .  36 .  . 100 85.00 64.0 57.00 . . . . . . . . . . 100 96 95 95 94 . . . . . . .   .  90.0 44.0  4.0  3.0  90  650.0 1.01 10.80  6.63 0.2600 0.32 .0001756
 5 7040000 1978  3 22  830.0 5600.0 48.2 1723.68 . 114 . 100  99 61.00 39.0 32.00 . . . . . . . . . . . . . . . . . . . . . . . . 100  99.0 94.0 37.0  6.0 220 3110.0 1.80 28.70 14.14 0.1400 0.16 .0003339
 6 7040000 1978  4 18 1515.0 1250.0 61.7  600.75 . 178 . . . . . . . . 100  99  44.0 24 21.0 . . . . . . . . . . . . . . . . . . 100  96.0 49.0  8.0  5.0 126 1000.0 1.16 13.30  8.57 0.2500 0.27 .0001906
 7 7040000 1978  5 17 1515.0  352.0 66.2  233.08 . 246 . . . . . . . . . 100  97.0 52 37.0 . . . . . . . . . . . . . . . . . . .  98  95.0 78.0 17.0  0.0  86  472.0 0.75  8.60  5.49 0.1600 0.21 .0001726
 8 7040000 1978  6 22  930.0   28.1 75.2    7.82 .  76 . 100  99 91.00 62.0 56.00 . . . . . . . . . . . . . . . . . . . . . . . . 100  95.0 53.0 25.0 15.0  61  223.0 0.17  5.40  3.66 0.2100 0.31 .0001525
 9 7040000 1978  7 26  740.0  433.0 80.6  122.76 . 105 . 100  99 90.00 72.0 63.00 . . . . . . . . . . . . . . . . . . . . . . . . 100  97.0 61.0 13.0 11.0  85  504.0 0.86  9.00  5.93 0.2000 0.27 .0001764
10 7040000 1978  8 31 1650.0  475.0 67.1  374.49 . 292 . 100  99 91.00 77.0 70.00 . . . . . . . . . . . . . . . . . . . . . . . . 100  90.0 87.0 50.0 44.0 103  698.0 0.68  9.40  6.78 0.0700 0.14 .0001196
11 7040000 1978  9 20 1000.0  195.0 78.0   70.03 . 133 . 100  99 90.00 71.0 57.00 . . . . . . . . . . . . . . . . . . . . . . . .  99  96.0 70.0 39.0 24.0 175  334.0 0.58  6.70  1.91 0.1600 0.22 .0001633
12 7040000 1978 10 19 1300.0  120.0 60.8   22.46 .  65 .  . 100 83.00 56.0 41.00 . . . . . . . . . . . . . . . . . . . . . . . . . 100  86.0 36.0 15.0 11.0  69  269.0 0.40  6.00  3.90 0.2800 0.35 .0001599
13 7040000 1978 11 21 1030.0  463.0 50.0  178.76 . 143 . . . . . . . . 100  95.0 73 66.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 73.0 29.0 20.0  91  540.0 0.86  9.20  5.93 0.1600 0.21 .0001773
14 7040000 1978 12 19 1630.0 1740.0 39.2  319.46 .  68 . . . . . . . . 100  95.0 56 46.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 82.0 60.0 21.0 115 1100.0 1.47 13.70 14.26 0.0900 0.13 .0002105
15 7040000 1979  1 25 1430.0 2020.0 35.6  256.34 .  47 .  . 100 92.00 60.0 51.00 . . . . . . . . . . . . . . . . . . . . . . .   .    .    .    .    .  138 1560.0 1.29 15.70 11.34    .      .   .0002068
16 7040000 1979  3 22  900.0 5160.0 50.0  955.44 .  67 . . . . . . . . 100  99.0 72 63.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 71.0 25.0 22.0 198 2730.0 1.66 27.50 13.79 0.1700 0.22 .0002407
17 7040000 1979  4 20 1000.0 8520.0 55.4 1954.37 .  87 . . . . . . . . 100  94.0 65 57.0 . . . . . . . . . . . . . . . . . . . . 100  97.0 56.0  2.0  2.0 305 4250.0 1.96 29.60 13.93 0.2300 0.28 .0002421
18 7040000 1979  5 24  900.0 2550.0 64.2  402.57 .  42 . . . . . . . . 100  95.0 89 83.0 . . . . . . . . . . . . . . . . . . . . 100.0 96.0 57.0 39.0 145 1930.0 1.84 22.90 13.31 0.0900 0.15 .0002264
19 7040000 1979  6 21  930.0  160.0 76.1   27.22 .  60 . . . . . . . . . 100.0 98 95.0 . . . . . . . . . . . . . . . . . . . . 100.0 97.0 74.0 65.0  75  323.0 0.52  7.20  4.31 0.0000 0.15 .0001661
20 7040000 1979  7 25 1330.0   75.0 80.6   11.75 .  58 . . . . . . . . 100  97.0 92 89.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 82.0  9.0  3.0  80  246.0 0.30  6.00  3.08 0.1600 0.18 .0001519
21 7040000 1979  8 22  915.0  101.0 78.8   11.73 .  43 . . . . . . . . 100  89.0 71 67.0 . . . . . . . . . . . . . . . . . . . . 100  96.0 44.0  7.0  4.0  47  247.0 0.41  6.30  3.69 0.1400 0.17 .0001579
22 7040000 1979  9 19  930.0   65.0 78.7    8.07 .  46 . . . . . . . . . 100.0 92 83.0 . . . . . . . . . . . . . . . . . . . . 100  97.0 73.0 27.0 16.0  72  249.0 0.26  5.80  3.46 0.1700 0.21 .0001549
23 7040000 1979 11 20  930.0  303.0 51.8   29.45 .  36 . . . . . . . . 100  96.0 83 74.0 . . . . . . . . . . . . . . . . . . . . 100  98.0 62.0 25.0 16.0  90  522.0 0.58  8.90  5.80 0.1700 0.26 .0001722
24 7040000 1979 12 19 1430.0 2060.0 37.4  155.74 .  28 . . . . . . . . 100  95.0 90 84.0 . . . . . . . . . . . . . . . . . . . . 100.0 92.0 35.0 18.0 120 1350.0 1.55 16.10 11.25 0.1440 0.17 .0002140
25 7040000 1980  1 25  850.0  600.0 41.0   29.55 .  18 . . . . . . . . 100  99.0 95 88.0 . . . . . . . . . . . . . . . . . . . . 100.0 99.0 63.0 35.0  92  721.0 0.84 11.70  7.84 0.0854 0.13 .0001796
26 7040000 1980  2 19 1345.0 2650.0 36.5  343.44 .  48 . . . . . . . . 100  98.0 87 75.0 . . . . . . . . . . . . . . . . . . .   .    .    .    .    .  132 1670.0 1.59 19.20 12.65    .      .   .0002119
27 7040000 1980  3 30    0.9 1270.0 40.2   89.15 .  26 . . . . . . . . 100  99.0 96 94.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 88.0  7.0  3.0 126 1460.0 1.20 13.50  8.41 0.1600 0.18 .0001964
28 7040000 1980  4 23 1430.0 1700.0 66.2  148.99 .  31 . . . . . . . . 100  99.0 95 91.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 64.0  6.0  2.0 116 1450.0 1.23 16.60 12.50 0.2000 0.25 .0002112
29 7040000 1980  5 21 1330.0 1140.0 73.4  132.85 .  43 . . . . . . . . 100  98.0 93 86.0 . . . . . . . . . . . . . . . . . . . . 100.0 98.0 60.0 41.0 110 1100.0 0.97 14.00 10.73 0.0000 0.14 .0001970
30 7040000 1980  6 18 1400.0  114.0 77.0   11.70 .  38 . . . . . . . . 100  99.0 98 98.0 . . . . . . . . . . . . . . . . . . . . 100.0 96.0 39.0 26.0  85  187.0 0.61  3.60  2.20 0.1300 0.16 .0001622
31 7040000 1980  7 30 1330.0  121.0 86.0   14.70 .  45 . . . . . . . . . 100.0 98 87.0 . . . . . . . . . . . . . . . . . . . . 100.0 99.0 52.0 16.0  66  272.0 0.44  6.60  4.12 0.1300 0.15 .0001602
32 7040000 1980  8 21 1000.0   46.0 84.2    5.09 .  41 . . . . . . . . 100  98.0 94 89.0 . . . . . . . . . . . . . . . . . . . . 100  93.0 61.0 11.0  6.0  74  202.0 0.23  6.00  2.73 0.2000 0.27 .0001567
33 7040000 1980  9 17  800.0  100.0 76.3   16.20 .  60 . . . . . . . . 100  99.0 98 91.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 95.0 26.0 13.0  47  183.0 0.54  5.60  3.09 0.1500 0.17 .0001576
34 7040000 1980 10 21  845.0   99.0 59.0   11.23 .  42 . . . . . . . . 100  98.0 95 90.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 93.0 32.0 16.0  49  170.0 0.58  5.44  3.47 0.1500 0.17 .0001505
35 7040000 1980 11 19  900.0  227.0 46.4   16.55 .  27 . . . . . . . . 100  97.0 90 81.0 . . . . . . . . . . . . . . . . . . . . 100  98.0 85.0 30.0  4.0  73  333.0 0.68  7.30  4.56 0.1700 0.19 .0001681
36 7040000 1980 12 17  930.0 1720.0 42.8  167.18 .  36 . . . . . . . . 100  97.0 94 88.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 80.0 59.0 58.0 136 1290.0 1.33 14.50  9.49 0.0625 0.14 .0002124
37 7040000 1981  1 22  945.0   88.0 37.4    4.75 .  20 . . . . . . . . 100  98.0 78 62.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 91.0 54.0 38.0  50  172.0 0.51  5.50  3.44 0.1200 0.16 .0001572
38 7040000 1981  2 18  840.0  550.0 41.0   39.17 .  26 . . . . . . . . 100  97.0 86 77.0 . . . . . . . . . . . . . . . . . . . . 100  91.0 65.0 12.0  9.0  90  610.0 0.91 10.10  6.78 0.2600 0.30 .0001779
39 7040000 1981  3 25  900.0  378.0 50.9   46.95 .  46 . . . . . . . . 100  97.0 91 81.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 90.0 34.0 20.0  90  565.0 0.67  9.70  6.28 0.1500 0.17 .0001767
40 7040000 1981  4 22  815.0  130.0 62.6   23.52 .  67 . . . . . . . . 100  99.0 97 94.0 . . . . . . . . . . . . . . . . . . . . 100.0 98.0 45.0 14.0  71  282.0 0.46  6.60  3.97 0.1300 0.16 .0001547
41 7040000 1981  5 21 1000.0 3030.0 61.7  425.41 .  52 . . . . . . . . 100  98.0 97 91.0 . . . . . . . . . . . . . . . . . . . . 100  98.0 79.0 31.0 20.0 165 1770.0 1.71 19.20 12.21 0.1600 0.19 .0002231
42 7040000 1981  6 17  930.0 2860.0 75.2  471.44 .  61 . . . . . . . . 100  98.0 93 85.0 . . . . . . . . . . . . . . . . . . . . 100  94.0 48.0  7.0  4.0 155 1770.0 1.62 19.60 11.42 0.2600 0.28 .0002192
43 7040000 1981  7 23  930.0 2460.0 82.4  723.90 . 109 . . . . . . . . 100  97.0 73 69.0 . . . . . . . . . . . . . . . . . . . . 100  98.0 60.0  1.0  1.0 117 1380.0 1.78 17.70 11.79 0.2200 0.27 .0002413
44 7040000 1981  8 19  830.0  252.0 75.2   41.50 .  61 . . . . . . . . 100  96.0 97 95.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 73.0  6.0  5.0  36  338.0 0.75  7.10  4.45 0.1800 0.24 .0001620
45 7040000 1981  9 24  800.0 1730.0 68.0  154.14 .  33 . . . . . . . . 100  99.0 69 29.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 94.0 35.0 30.0 135 1230.0 1.41 15.90  9.11 0.1500 0.17 .0002110
46 7040000 1981 10 21  915.0  101.0 59.0    6.82 .  25 . . . . . . . . 100  98.0 94 81.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 85.0 33.0 30.0  60   93.2 1.00  2.66  1.55 0.0950 0.14 .0001581
47 7040000 1981 11 17  945.0  197.0 51.8   14.36 .  27 . . . . . . . . 100  97.0 95 88.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 87.0  9.0  6.0  70  278.0 0.71  7.10  3.97 0.1700 0.19 .0001676
48 7040000 1981 12 16 1100.0  302.0 41.0    8.97 .  11 . . . . . . . . 100  97.0 87 67.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 85.0 19.0 11.0  80  501.0 0.60  8.80  5.69 0.1600 0.19 .0001751
49 7040000 1982  2 24  945.0 6150.0 44.6  664.20 .  40 . . . . . . . 100  98  89.0 72 65.0 . . . . . . . . . . . . . . . . . . . . 100  97.0 45.0  2.0  2.0 235 2900.0 1.92 27.00 13.62 0.2700 0.31 .0002401
50 7040000 1982  3 17  830.0 3650.0 57.2  817.97 .  83 . . . . . . . . 100  99.0 81 75.0 . . . . . . . . . . . . . . . . . . . . 100.0 84.0  5.0  2.0 155 2770.0 2.06 17.70 11.42 0.1700 0.19 .0002135
51 7040000 1982  4 20  800.0 1170.0 60.8  129.52 .  41 . . . . . . . . 100  98.0 81 75.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 71.0  4.0  2.0 115  647.0 1.81 12.00  5.45 0.1800 0.23 .0001904
52 7040000 1982  5 19  900.0  133.0 73.4   15.80 .  44 . . . . . . . 100  96  99.0 89 84.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 85.0 24.0 15.0  65  245.0 0.55  6.20  3.74 0.1600 0.18 .0001561
53 7040000 1982  6 22  845.0 2160.0 77.9  408.24 .  70 . . . . . . . . 100  98.0 95 84.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 73.0  2.0  2.0 140 1350.0 1.60 15.00  9.64 0.1800 0.22 .0002073
54 7040000 1982  7 21  845.0  115.0 82.4   11.80 .  38 . . . . . . . . 100  99.0 98 97.0 . . . . . . . . . . . . . . . . . . . . 100  99.0 97.0 47.0 29.0  63  114.0 1.01  2.82  1.81 0.1300 0.15 .0001591
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OBS	STATION	YEAR	MONTH	DAY	TIME	FLOW	TEMP	SEDFLOW	CHANNEL	CONC	SSSA	SSSB	SSSC	SSSD	SSSE	SSSF	SSFA	SSFB	SSFC	SSFD	SSFE	SSFF	BRSA	BRSB	BRSC	BRSD	BRSE	BRSF	BRSG	BRSH	BRSI	BRSJ	BRFA	BRFB	BRFC	BRFD	BRFE	BRFF	WIDTH	AREA	VEL	DEPMAX	DEPAVG	DFFITY	DSITY	SLOPE
55	7040000	1982	8	25	1100	123.0	78.8	31.55	.	95	.	.	.	.	.	.	.	.	100	99	97	96	.	.	.	.	.	.	.	.	.	.	.	100	99	61	3	3	60	111.0	0.15	2.68	1.85	0.20	0.26	.0001244
56	7040000	1982	9	22	815	2530.0	66.9	227.09	.	46	.	.	.	.	.	.	.	.	100	98	86	75	.	.	.	.	.	.	.	.	.	.	.	100	99	77	2	1	140	1620.0	1.56	18.50	11.57	0.17	0.20	.0002163
57	7040000	1982	10	19	1230	335.0	63.3	29.85	.	33	.	.	.	.	.	.	.	.	.	100	98	95	.	.	.	.	.	.	.	.	.	.	.	100	99	77	3	2	70	317.0	1.06	7.10	4.55	0.17	0.20	.0000001
58	7040000	1982	11	15	1400	320.0	46.2	77.45	.	31	.	.	.	.	.	.	.	.	100	94	75	66	.	.	.	.	.	.	.	.	.	.	.	100	99	79	2	2	75	252.0	0.93	7.50	4.55	0.17	0.20	.0001685
59	7040000	1982	11	29	1150	1020.0	47.3	154.22	.	56	.	.	.	.	.	.	.	.	100	99	97	66	.	.	.	.	.	.	.	.	.	.	.	100	98	56	4	3	100	702.0	1.30	11.30	7.82	0.22	0.27	.0001814
60	7040000	1983	1	30	1400	10400.0	47.8	3067.04	.	38	.	.	.	.	.	.	.	.	100	95	90	80	.	.	.	.	.	.	.	.	.	.	.	.	100	86	27	16	430	6140.0	1.69	20.90	14.20	0.15	0.17	.0002332
61	7040000	1983	2	14	1250	3560.0	43.7	444.53	.	49	.	.	.	.	.	.	.	.	100	97	76	66	.	.	.	.	.	.	.	.	.	.	.	.	100	83	7	2	160	2160.0	1.56	19.50	13.50	0.18	0.21	.0002325
62	7040000	1983	3	15	1430	1320.0	53.6	161.36	.	29	.	.	.	.	.	.	.	.	100	98	97	97	.	.	.	.	.	.	.	.	.	.	.	100	97	38	3	3	110	914.0	1.44	12.60	8.31	0.27	0.30	.0001945
63	7040000	1983	4	13	1630	2560.0	53.6	541.62	.	85	.	.	.	.	.	.	.	.	100	99	90	76	.	.	.	.	.	.	.	.	.	.	.	100	98	55	2	2	134	1600.0	1.48	16.30	11.94	0.25	0.27	.0002107
64	7040000	1983	5	9	1645	7000.0	63.5	585.90	.	31	.	.	.	.	.	.	.	.	100	95	84	70	.	.	.	.	.	.	.	.	.	.	.	100	83	15	0	0	243	3660.0	1.91	20.00	15.06	0.31	0.35	.0002338
65	7040000	1983	6	14	830	910.0	71.6	174.45	.	71	.	.	.	.	.	.	.	.	.	100	97	94	.	.	.	.	.	.	.	.	.	.	.	100	90	55	6	4	116	766.0	1.19	10.30	6.60	0.24	0.28	.0001829
66	7040000	1983	7	12	1300	170.0	84.2	27.87	.	58	.	.	.	.	.	.	.	.	100	90	89	88	.	.	.	.	.	.	.	.	.	.	.	100	99	96	18	4	63	235.0	0.76	5.00	3.73	0.16	0.17	.0000001
67	7040000	1983	8	8	1230	110.0	83.3	8.61	.	29	.	.	.	.	.	.	.	.	.	100	96	92	.	.	.	.	.	.	.	.	.	.	.	100	99	95	19	3	58	124.0	0.09	3.50	2.14	0.16	0.17	.0000001
68	7040000	1983	9	13	1400	61.0	80.6	4.28	.	26	.	.	.	.	.	.	.	.	100	98	98	97	.	.	.	.	.	.	.	.	.	.	100	99	99	94	18	5	51	83.0	0.73	2.58	1.64	0.16	0.17	.0000001
69	7040000	1983	10	20	900	321.0	62.6	32.07	.	37	.	.	.	.	.	.	.	.	100	99	98	98	.	.	.	.	.	.	.	.	.	.	.	100	98	75	33	17	78	361.0	0.89	6.70	4.83	0.17	0.21	.0000001
70	7040000	1983	11	9	1250	1770.0	57.2	449.25	.	94	.	.	.	.	.	.	.	.	.	100	97	89	.	.	.	.	.	.	.	.	.	.	100	99	98	92	29	15	126	1220.0	1.45	14.20	9.68	0.16	0.18	.0002141
71	7040000	1984	1	16	1330	4200.0	37.4	646.38	.	57	.	.	.	.	.	.	.	.	100	93	64	39	.	.	.	.	.	.	.	.	.	.	.	100	98	70	6	4	152	2250.0	1.08	21.10	14.67	0.18	0.22	.0002316
72	7040000	1984	2	13	1500	876.0	46.4	357.14	.	151	.	.	.	.	.	.	.	.	100	99	99	99	.	.	.	.	.	.	.	.	.	.	100	99	87	30	14	9	115	702.0	1.25	9.40	6.10	0.28	0.31	.0001268
73	7040000	1984	3	12	1325	2660.0	42.8	114.91	.	16	.	.	.	.	.	.	.	.	100	93	86	84	.	.	.	.	.	.	.	.	.	.	.	100	93	52	2	2	135	1450.0	1.83	15.40	10.74	0.25	0.29	.0002127
74	7040000	1984	4	16	1330	2200.0	56.3	221.32	.	28	.	.	.	.	.	.	.	.	100	92	72	55	.	.	100	85	83	.	.	.	.	.	.	82	81	64	10	9	165	1840.0	1.74	18.10	12.69	0.21	0.25	.0002192
75	7040000	1984	5	14	1330	2500.0	67.1	302.40	.	32	.	.	.	.	.	.	.	.	100	96	95	85	.	.	.	.	.	.	.	.	.	.	.	100	99	61	3	2	149	1660.0	1.08	18.20	12.40	0.23	0.25	.0002170
76	7040000	1984	6	4	1330	956.0	73.4	144.55	.	56	.	.	.	.	.	.	.	.	100	96	84	74	.	.	.	.	.	.	.	.	.	.	.	100	96	58	3	2	121	730.0	1.31	9.50	6.03	0.23	0.27	.0001817
77	7040000	1984	6	18	1330	252.0	81.5	36.74	.	54	.	.	.	.	.	.	.	.	.	100	99	98	.	.	.	.	.	.	.	.	.	.	.	100	98	68	8	4	98	300.0	0.82	5.70	3.42	0.22	0.24	.0001579
78	7040000	1984	7	16	1130	256.0	82.4	22.12	.	32	.	.	.	.	.	.	.	.	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	100	98	64	10	5	98	290.0	0.86	5.40	3.31	0.22	0.25	.0000001
79	7040000	1984	8	13	1130	78.0	82.4	10.53	.	50	.	.	.	.	.	.	.	.	.	100	94	84	.	.	.	.	.	.	.	.	.	.	.	100	98	73	15	8	75	150.0	0.52	3.70	2.00	0.21	0.24	.0000001
80	7040000	1984	9	11	1130	148.0	74.3	25.57	.	64	.	.	.	.	.	.	.	.	100	98	97	96	.	.	.	.	.	.	.	.	.	.	.	100	98	68	30	6	82	199.0	0.74	4.20	2.43	0.23	0.24	.0000001
81	7040000	1984	10	22	1315	2960.0	62.6	479.52	67	60	.	.	.	.	.	.	.	.	.	100	94	86	.	.	.	.	.	.	.	.	.	.	.	100	97	75	7	4	143	1660.0	1.78	16.00	11.61	0.21	0.22	.0000001
82	7040000	1984	11	27	1430	3750.0	40.2	554.56	67	52	.	.	.	.	.	.	.	.	.	100	91	86	.	.	.	.	.	.	.	.	.	.	.	100	99	75	2	1	155	2000.0	1.90	20.00	13.43	0.21	0.23	.0001813
83	7040000	1984	12	17	1630	3850.0	46.4	413.64	67	40	.	.	.	.	.	.	.	.	100	92	77	64	.	.	.	.	.	.	.	.	.	.	100	99	92	51	3	3	154	1990.0	2.02	18.40	12.67	0.24	0.29	.0002227
84	7040000	1985	1	14	1600	7900.0	37.4	911.12	67	46	.	.	.	.	.	.	.	100	98	89	50	44	.	.	.	.	.	.	.	.	.	.	.	100	90	41	8	5	100	3240.0	2.46	27.20	18.00	0.27	0.31	.0002345
85	7040000	1985	2	11	1500	1130.0	35.8	143.40	67	47	.	.	.	.	.	.	.	.	100	91	82	74	.	100	68	65	37	.	.	.	.	.	.	36	33	22	3	2	115	822.0	1.37	11.10	7.15	5.20	8.70	.0001650
86	7040000	1985	3	11	1600	4790.0	54.0	633.72	67	49	.	.	.	.	.	.	.	.	100	99	94	86	.	100	63	42	33	.	.	.	.	.	.	32	29	22	1	1	156	2240.0	2.14	21.10	14.36	6.00	9.70	.0002177
87	7040000	1985	4	8	1500	7410.0	52.7	1500.53	67	75	.	.	.	.	.	.	.	.	100	97	93	82	.	.	100	75	70	.	.	.	.	.	.	69	66	42	1	1	175	3000.0	2.41	26.10	17.60	0.35	0.50	.0002357
88	7040000	1985	5	15	1500	2910.0	68.0	267.14	67	34	.	.	.	.	.	.	.	.	100	98	95	90	.	.	.	100	90	.	.	.	.	.	.	89	79	50	11	9	140	1610.0	1.81	17.00	11.50	0.25	0.34	.0002109
89	7040000	1985	6	11	1430	3320.0	73.4	968.11	67	108	.	.	.	.	.	.	.	.	100	96	77	61	.	.	.	.	.	.	.	.	.	.	.	100	99	75	2	1	142	1000.0	1.84	18.10	12.60	0.21	0.23	.0002201
90	7040000	1985	7	15	1230	3400.0	77.0	667.12	67	71	.	.	.	.	.	.	.	.	100	98	97	84	.	.	.	100	97	.	.	.	.	.	.	97	91	65	8	5	143	1760.0	1.98	18.00	12.81	0.23	0.25	.0000001
91	7040000	1985	8	12	1300	1240.0	78.8	237.71	67	71	.	.	.	.	.	.	.	.	.	100	99	98	.	.	.	.	.	.	.	.	.	.	.	100	97	67	3	2	118	858.0	1.65	11.80	7.67	0.22	0.24	.0000001
92	7040000	1985	9	16	1230	513.0	68.0	78.95	67	57	.	.	.	.	.	.	.	.	.	100	99	97	.	.	.	.	.	.	.	.	.	.	.	100	98	77	5	3	100	446.0	1.15	7.60	4.46	0.22	0.23	.0000001
93	7040000	1985	10	15	1230	214.0	62.6	27.73	67	48	.	.	.	.	.	.	.	.	.	100	97	94	.	.	.	.	.	.	.	.	.	.	.	100	99	90	25	15	80	242.0	0.88	5.50	3.63	0.19	0.21	.0000001
94	7040000	1985	11	18	1515	3630.0	55.6	548.86	67	56	.	.	.	.	.	.	.	.	.	100	92	81	.	.	.	.	.	.	.	.	.	.	.	100	94	54	4	3	152	1950.0	1.88	19.30	12.70	0.24	0.27	.0002273
95	7040000	1985	12	16	1600	4410.0	37.4	1131.17	67	95	.	.	.	.	.	.	.	.	100	95	65	47	.	.	.	.	.	.	.	.	.	.	100	99	72	24	12	12	160	2070.0	2.13	20.40	12.94	0.34	0.38	.0002293
96	7040000	1986	1	21	1530	2510.0	38.3	325.30	67	48	.	.	.	.	.	.	.	.	100	94	72	68	.	.	100	86	81	.	.	.	.	.	.	81	74	48	8	7	135	1350.0	1.86	15.50	10.00	0.26	0.38	.0002048
97	7040000	1986	2	18	1500	1710.0	37.4	129.20	67	28	.	.	.	.	.	.	.	.	100	95	90	89	.	.	.	.	.	.	.	.	.	.	.	100	98	66	1	1	125	1020.0	1.68	12.00	8.16	0.22	0.24	.0001884
98	7040000	1986	3	17	1530	3210.0	50.0	500.69	67	67	.	.	.	.	.	.	.	.	100	95	91	87	.	.	.	.	.	.	.	.	.	.	.	100	94	69	4	3	137	1470.0	1.77	16.20	10.73	0.22	0.24	.0002057
99	7040000	1986	4	21	1550	1960.0	55.4	428.65	67	81	.	.	.	.	.	.	.	.	.	100	97	95	.	.	.	.	.	.	.	.	.	.	.	100	98	51	3	3	127	1120.0	1.75	13.70	8.82	0.25	0.27	.0001729
100	7040000	1986	5	19	1430	440.0	64.4	155.65	67	131	.	.	.	.	.	.	.	.	.	100	97	95	.	.	.	.	.	.	.	.	.	.	.	100	98	70	10	7	96	387.0	1.14	7.30	4.03	0.23	0.24	.0001570
101	7040000	1986	6	16	1615	2920.0	80.6	922.43	67	117	.	.	.	.	.	.	.	.	100	97	86	70	.	.	.	.	.	.	.	.	.	.	.	100	96	52	5	4	142	1510.0	1.93	16.80	10.63	0.24	0.28	.0002122
102	7040000	1986	7	21	1200	228.0	79.7	30.78	67	50	.	.	.	.	.	.	.	.	.	100	98	95	.	.	.	.	.	.	.	.	.	.	.	100	98	69	10	8	85	243.0	0.94	6.20	2.86	0.23	0.24	.0000001
103	7040000	1986	8	26	1200	102.0	77.0	10.19	67	37	.	.	.	.	.	.	.	.	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	100	94	57	8	6	50	161.0	0.63	5.00	3.22	0.25	0.27	.0000001
104	7040000	1986	9	16	1230	54.0	67.1	6.05	67	47	.	.	.	.	.	.	.	.	100	96	90	83	.	.	.	.	.	.	.	.	.	.	.	100	98	54	6	5	62	66.7	0.81	2.75	1.08	0.24	0.27	.0000001
105	7040000	1986	10	21	1200	113.0	44.4	9.15	67	30	.	.	.	.	.	.	.	.	.	.	.	100	.	.	.	.	.	.	.	.	.	.	.	100	99	67	4	3	55	179.0	0.63	4.90	3.25	0.23	0.25	.0000001
106	7040000	1986	11	17	1515	47.2	48.2	2.29	67	18	.	.	.	.	.	.	.	.	.	100	98	83	.	.	.	.	.	.	.	.	.	.	.	100	98	58	1	1	55	147.0	0.32	4.20	2.67	0.22	0.26	.0001448
107	7040000	1986	12	15	1500	1320.0	41.9	139.00	67	39	.	.	.	.	.	.	.	.	100	92	81	79	.	.	.	.	.	.	.	.	.	.	.	100	97	47	1	1	120	814.0	1.62	11.10	6.78	0.26	0.30	.0001870
108	7040000	1987	1	20	1600	540.0	39.2	31.07	67	21	.	.	.	.	.	.	.	.	.	100	99	98	.	.	.	.	.	.	.	.	.	.	.	.	100	99	89	58	110	470.0	1.17	8.80	4.27	0.06	0.07	.0001695

OBS	STATION	YEAR	MONTH	DAY	TIME	FLOW	TEMP	SEDFLOW	CHANNEL	CONC	SSSA	SSSB	SSSC	SSSD	SSSE	SSSF	SSFA	SSFB	SSFC	SSFD	SSFE	SSFF
109	7040000	1987	2	23	1500	1540.0	35.6	104.922	67	29	.	.	.	.	.	.	.	.	100	98	79	77
110	7040000	1987	3	16	1415	1710.0	51.8	244.701	67	53	.	.	.	.	.	.	.	.	100	96	89	85
111	7040000	1987	4	13	1445	608.0	59.9	65.664	67	40	.	.	.	.	.	.	.	.	.	100	95	93
112	7040000	1987	5	18	1600	86.0	77.0	46.200	67	199	.	.	.	.	.	.	.	100	99	51	36	34
113	7040000	1987	6	15	1500	85.0	73.4	11.705	67	51	.	.	.	.	.	.	.	.	100	96	81	81
114	7040000	1987	7	13	1345	366.0	86.0	148.910	67	72	.	.	.	.	.	.	.	.	.	100	95	95
115	7040000	1987	8	18	1200	410.0	84.2	86.346	67	78	.	.	.	.	.	.	.	.	100	99	97	95
116	7040000	1987	9	15	1440	309.0	78.8	49.224	67	59	.	.	.	.	.	.	.	.	.	100	96	91
117	7040000	1987	10	13	1330	70.3	55.4	6.366	67	23	.	.	.	.	.	.	.	.	.	100	97	97
118	7040000	1987	11	17	1500	60.0	55.6	4.212	67	26	.	.	.	.	.	.	.	.	.	100	98	98
119	7040000	1987	12	7	1445	1010.0	45.5	109.000	67	40	.	.	.	.	.	.	.	.	100	98	96	96
120	7040000	1988	1	20	1600	4260.0	37.4	425.574	67	37	.	.	.	.	.	.	.	.	100	91	83	83
121	7040000	1988	2	16	1445	2870.0	36.5	167.670	67	30	.	.	.	.	.	.	.	.	100	86	70	70
122	7040000	1988	3	14	1455	2200.0	50.0	314.820	67	53	.	.	.	.	.	.	.	.	100	96	95	92
123	7040000	1988	4	11	1530	3150.0	51.9	425.250	67	50	.	.	.	.	.	.	.	.	.	100	94	90
124	7040000	1988	5	24	1445	310.0	70.7	66.123	67	79	.	.	.	.	.	.	.	.	100	97	82	79
125	7040000	1988	6	20	1500	194.0	82.4	26.714	67	51	.	.	.	.	.	.	.	.	.	100	99	98
126	7040000	1988	7	19	1315	171.0	82.4	59.090	67	128	.	.	.	.	.	.	.	.	100	98	97	96
127	7040000	1988	8	15	1300	65.0	81.6	7.266	67	39	.	.	.	.	.	.	.	.	.	100	98	97
128	7040000	1988	9	12	1215	144.0	75.2	21.773	67	56	.	.	.	.	.	.	.	.	100	97	94	94

OBS	BHSA	BHSB	BHSC	BHSD	BHSE	BHSF	BHSG	BHSH	BHSI	BHSJ	BHFA	BHFB	BHFC	BHFD	BHFE	BHFF	WIDTH	AREA	VEL	DEPTH	DEPAVG	DFIFTY	DSIXTY	SLOPE
109	.	.	.	.	.	.	.	.	.	.	.	100	99	66	1	1	120	855.0	1.57	11.90	7.13	0.22	0.25	.0001870
110	.	.	.	.	.	.	.	.	.	.	.	100	95	51	4	3	125	1010.0	1.69	13.00	8.08	0.25	0.27	.0001933
111	.	.	.	.	.	.	.	.	.	.	.	100	99	72	6	5	105	464.0	1.32	8.50	4.38	0.21	0.24	.0001687
112	.	.	.	.	.	.	.	.	.	.	.	100	96	52	4	2	56	144.0	0.60	3.90	2.57	0.24	0.27	.0001441
113	.	100	73	62	31	.	.	.	.	.	.	30	24	17	0	6	55	167.0	0.51	4.00	3.04	5.70	7.90	.0001465
114	.	.	.	.	.	.	.	.	.	.	.	100	98	49	4	3	110	563.0	1.36	8.90	5.12	0.25	0.31	.0000001
115	.	.	.	.	.	.	.	.	.	.	.	100	99	75	12	9	95	330.0	1.24	6.70	3.47	0.20	0.22	.0000001
116	.	.	.	.	.	.	.	.	.	.	.	100	99	86	15	8	90	259.0	1.19	5.50	2.88	0.20	0.22	.0000001
117	.	.	.	.	.	.	.	.	.	.	.	100	99	78	7	6	51	69.0	1.01	2.90	1.37	0.21	0.23	.0000001
118	.	.	.	.	.	.	.	.	.	.	.	100	98	80	34	24	48	57.7	1.04	2.24	1.20	0.16	0.18	.0001352
119	.	.	.	.	.	.	.	.	.	.	.	100	98	42	1	1	110	647.0	1.56	9.70	5.88	0.27	0.30	.0001723
120	.	.	.	100	90	.	.	.	.	.	.	89	80	29	6	6	150	2010.0	2.11	19.70	13.40	0.29	0.34	.0001887
121	.	100	71	52	41	.	.	.	.	.	.	41	41	39	23	2	129	1200.0	1.72	15.00	9.30	3.00	6.90	.0001904
122	.	.	.	.	.	.	.	.	.	.	.	100	90	55	15	11	133	1170.0	1.85	13.90	8.80	0.24	0.28	.0001945
123	.	.	.	.	.	.	.	.	.	.	.	100	96	52	7	6	142	1540.0	2.05	16.40	10.85	0.25	0.27	.0002028
124	.	.	.	.	.	.	.	.	.	.	.	100	99	68	4	3	96	343.0	0.90	6.40	3.57	0.23	0.24	.0001531
125	.	.	.	.	.	.	.	.	.	.	.	100	98	84	14	9	88	262.0	0.74	5.30	2.98	0.20	0.22	.0001523
126	.	.	.	.	.	.	.	.	.	.	.	100	99	76	18	13	85	230.0	0.74	5.00	2.71	0.20	0.23	.0000001
127	.	.	.	.	.	.	.	.	.	.	.	100	96	71	25	15	44	65.5	1.09	2.02	1.44	0.20	0.23	.0000001
128	.	.	.	.	.	.	.	.	.	.	.	100	98	79	25	15	68	212.0	0.60	3.00	3.12	0.19	0.22	.0000001

OBS	STATION	YEAR	MONTH	DAY	TIME	FLOW	TEMP	SEDFLOW	CHANNEL	CONC	SSSA	SSSB	SSSC	SSSD	SSSE	SSSF	SSFA	SSFB	SSFC	SSFD	SSFE	SSFF	SKSA	SKSB	SKSC	SKSD	SKSE	SKSF	SKSG	SKSH	SKSI	SKSJ	SKFA	SKFB	SKFC	SKFD	SKFE	SKFF	WIDTH	AREA	VEL	DEPMAX	DEPAVG	VISCOSIT
54	7047904	1982	4	6	1500	7490	51.6	6467.12	0	341	0	0	0	0	0	0	0	0	100	99	98	96	0	0	0	0	0	0	0	0	0	0	0	100	95	36	7	2	239	4440	1.85	26.9	16.90	.00001333
55	7047904	1982	5	4	1230	2940	71.6	833.49	0	105	0	0	0	0	0	0	0	0	100	97	95	94	0	0	0	0	0	0	0	0	0	0	0	100	70	20	0	5	174	1990	1.48	16.0	11.40	.00001032
56	7047904	1982	6	9	1400	1580	81.5	452.20	0	106	0	0	0	0	0	0	0	0	100	99	97	96	0	0	0	0	0	0	0	0	0	0	0	100	90	62	0	2	174	2070	0.76	16.1	11.90	.00000909
57	7047904	1982	7	6	1045	1850	86.6	494.50	0	99	0	0	0	0	0	0	0	0	100	99	99	98	0	0	0	0	0	0	0	0	0	0	0	100	87	25	2	2	180	1760	1.05	15.0	9.78	.00000664
58	7047904	1982	8	3	1100	1460	84.2	413.91	0	105	0	0	0	0	0	0	0	0	100	98	97	96	0	0	0	0	0	0	0	0	0	0	0	100	80	26	2	2	168	1560	0.94	13.3	9.29	.00000888
59	7047904	1982	9	14	1100	2010	78.8	646.04	0	119	0	0	0	0	0	0	0	100	98	97	96	90	0	0	0	0	0	0	0	0	0	0	0	100	97	64	6	2	165	1530	1.25	14.1	9.27	.00000943
60	7047904	1982	11	15	1330	610	54.0	47.76	0	29	0	0	0	0	0	0	0	0	100	93	85	82	0	0	0	0	0	0	0	0	0	0	0	100	82	12	1	1	162	1330	0.46	11.7	8.21	.00001410
61	7047904	1982	11	30	845	10400	48.2	13169.52	0	469	0	0	0	0	0	0	0	0	100	98	84	78	0	0	0	0	0	0	0	0	0	0	0	100	69	5	2	1	210	3510	2.96	27.4	16.70	.00001461
62	7047904	1983	1	14	800	21200	41.9	8013.60	0	140	0	0	0	0	0	0	0	0	100	97	74	65	0	0	0	0	0	0	0	0	0	0	0	100	70	30	0	0	344	5940	3.57	34.0	19.50	.00001613
63	7047904	1983	2	15	1615	4360	48.2	812.27	0	69	0	0	0	0	0	0	0	0	100	97	89	79	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	180	2260	1.23	19.1	12.60	.00001461
64	7047904	1983	3	17	800	2190	57.2	437.56	0	74	0	0	0	0	0	0	0	0	100	98	97	94	0	0	0	0	0	0	0	0	0	0	100	97	77	26	15	8	171	1940	1.13	17.0	11.30	.00001275
65	7047904	1983	4	23	1100	12100	61.7	6566.67	0	201	0	0	0	0	0	0	0	0	100	99	98	91	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	265	4410	2.74	29.0	15.50	.00001185
66	7047904	1983	5	11	1500	26300	68.0	14770.00	0	208	0	0	0	0	0	0	0	0	100	99	82	76	0	0	0	0	0	0	0	0	0	0	0	100	99	63	1	1	335	7790	3.38	41.0	23.30	.00001090
67	7047904	1983	6	16	1200	8150	73.4	7195.64	0	327	0	0	0	0	0	0	0	0	100	99	97	94	0	0	0	0	0	0	0	0	0	0	0	100	80	20	16	14	266	3640	2.44	23.4	14.76	.00001020
68	7047904	1983	11	7	930	1110	54.2	212.79	0	71	0	0	0	0	0	0	0	0	100	98	93	85	0	0	0	0	0	0	0	0	0	0	100	99	80	25	9	7	164	1550	0.72	14.3	9.45	.00001256
69	7047904	1984	1	25	1330	13300	33.8	5530.14	0	154	0	0	0	0	0	0	0	0	100	98	57	46	0	0	0	0	0	0	0	0	0	0	100	98	62	29	15	13	200	3730	3.56	26.9	17.90	.00001844
70	7047904	1984	2	16	1200	16300	55.4	16512.18	0	378	0	0	0	0	0	0	0	0	100	99	88	88	0	0	0	0	0	0	0	0	0	0	0	100	98	73	1	1	200	3320	3.10	24.6	16.60	.00001314
71	7047904	1984	3	15	815	5610	46.4	1040.29	0	70	0	0	0	0	0	0	0	0	100	99	98	96	0	0	0	0	0	0	0	0	0	0	0	100	99	94	24	0	287	2000	1.94	23.0	10.00	.00001512
72	7047904	1984	4	19	810	10000	59.0	2133.00	0	79	0	0	0	0	0	0	0	100	98	97	95	93	0	0	0	0	0	0	0	0	0	0	100	99	79	1	0	0	298	4950	2.02	29.0	16.60	.00001236
73	7047904	1984	5	17	830	21300	64.0	5574.13	0	143	0	0	0	0	0	0	0	0	100	99	96	92	0	0	0	0	0	0	0	0	0	0	0	100	90	5	2	1	328	7400	2.88	39.5	22.60	.00001090
74	7047904	1984	6	6	1320	6260	77.0	2940.95	0	174	0	0	0	0	0	0	0	0	100	99	98	96	0	0	0	0	0	0	0	0	0	0	0	100	98	2	0	0	188	3120	2.01	24.0	16.60	.00000968
75	7047904	1984	6	20	1115	2290	84.0	315.33	0	51	0	0	0	0	0	0	0	100	98	97	92	85	0	0	0	0	0	0	0	0	0	0	0	100	80	6	3	2	172	2010	1.14	16.2	11.70	.00000668
76	7047904	1984	11	30	900	9230	46.4	7376.62	67	296	0	0	0	0	0	0	0	0	100	98	76	70	0	0	0	0	0	0	0	0	0	0	0	100	54	12	1	1	230	3720	2.44	25.8	16.20	.00001512
77	7047904	1985	1	17	830	21400	32.9	6240.24	67	108	0	0	0	0	0	0	0	0	100	98	48	44	0	0	0	0	0	0	0	0	0	0	100	99	70	52	45	34	302	6260	3.02	35.5	20.70	.00001897
78	7047904	1985	3	14	900	15900	51.8	3391.47	67	79	0	0	0	0	0	0	0	0	100	98	92	87	0	0	0	0	0	0	0	0	0	0	0	100	87	11	1	1	307	5000	2.70	25.3	19.20	.00001371
79	7047904	1985	4	11	900	15800	57.2	9598.50	67	225	0	0	0	0	0	0	0	0	100	99	90	75	0	0	0	0	0	0	0	0	0	0	0	100	82	14	4	1	290	5330	2.96	34.0	18.40	.00001275
80	7047904	1985	5	16	930	12200	69.8	6686.82	67	203	0	0	0	0	0	0	0	0	100	99	89	84	0	0	0	0	0	0	0	0	0	0	0	100	86	7	1	0	240	4020	3.03	26.0	16.80	.00001064
81	7047904	1985	6	13	1100	3950	71.6	1578.42	67	148	0	0	0	0	0	0	0	0	100	98	82	77	0	0	0	0	0	0	0	0	0	0	0	100	98	72	10	16	189	2400	1.65	18.0	12.70	.00001452
82	7047904	1985	11	20	1100	3260	56.3	1564.56	67	180	0	0	0	0	0	0	0	0	100	99	90	83	0	0	0	0	0	0	0	0	0	0	100	99	96	54	1	1	174	2140	1.52	16.7	12.30	.00001294
83	7047904	1985	12	19	830	7920	32.0	3699.43	67	173	0	0	0	0	0	0	0	0	100	99	89	76	0	0	0	0	0	0	0	0	0	0	0	100	79	23	10	9	236	3890	2.04	26.2	14.50	.00001931
84	7047904	1986	1	24	900	6130	39.2	2300.59	67	139	0	0	0	0	0	0	0	0	100	95	50	40	0	0	0	0	0	0	0	0	0	0	0	100	95	44	2	1	264	2820	2.17	20.8	13.80	.00001697
85	7047904	1986	2	21	830	8140	49.1	3470.33	67	147	0	0	0	0	0	0	0	0	100	98	89	81	0	0	0	0	0	0	0	0	0	0	0	100	91	39	3	2	229	3430	2.37	22.9	15.00	.00001435
86	7047904	1986	3	20	800	9190	50.0	7667.22	67	309	0	0	0	0	0	0	0	0	100	98	89	80	0	0	0	0	0	0	0	0	0	0	0	100	87	9	3	1	225	3660	2.51	24.0	16.30	.00001410
87	7047904	1986	4	24	930	6470	55.6	3895.59	67	223	0	0	0	0	0	0	0	0	100	98	88	81	0	0	0	0	0	0	0	0	0	0	0	100	95	24	6	3	195	2660	2.45	20.0	15.60	.00001333
88	7047904	1986	5	22	900	16200	63.5	17058.60	67	390	0	0	0	0	0	0	0	0	100	97	84	74	0	0	0	0	0	0	0	0	0	0	0	100	93	40	12	2	244	4440	4.01	27.1	16.80	.00001153
89	7047904	1986	6	19	930	11200	70.8	5605.12	67	184	0	0	0	0	0	0	0	0	100	97	88	70	0	0	0	0	0	0	0	0	0	0	100	99	85	8	3	1	240	4120	2.72	27.2	17.20	.00000943
90	7047904	1986	11	19	1000	550	50.0	119.02	67	79	0	0	0	0	0	0	0	0	100	96	72	62	0	0	0	0	0	0	0	0	0	0	0	100	96	68	36	5	170	1700	0.31	14.9	10.50	.00001410
91	7047904	1986	12	18	815	3600	44.6	1234.44	67	127	0	0	0	0	0	0	0	0	100	99	99	98	0	0	0	0	0	0	0	0	0	0	0	100	90	7	5	5	170	1700	0.31	14.9	10.50	.00001557
92	7047904	1987	1	23	745	718	36.5	94.99	67	49	0	0	0	0	0	0	0	0	0	100	98	95	0	0	0	0	0	0	0	0	0	0	0	100	97	83	11	4	180	1760	0.41	13.5	9.78	.00001764
93	7047904	1987	2	25	1330	2540	39.2	576.07	67	84	0	0	0	0	0	0	0	0	100	98	95	90	0	0	0	0	0	0	0	0	0	0	0	100	82	8	2	1	170	2050	1.24	15.8	12.10	.00001697
94	7047904	1987	3	19	1045	8770	57.2	11863.18	67	501	0	0	0	0	0	0	0	0	100	98	89	81	0	0	0	0	0	0	0	0	0	0	0	100	70	11	4	2	223	3940	2.25	27.3	17.70	.00001275
95	7047904	1987	4	16	930	3230	59.0	1081.40	67	124	0	0	0	0	0	0	0	0	100	99	96	90	0	0	0	0	0	0	0	0	0	0	0	0	100	62	2	1	181	2380	1.36	18.3	13.10	.00001256
96	7047904	1987	5	21	900	836	79.7	144.46	67	64	0	0	0	0	0	0	0	0	0	100	98	98	0	0	100	80	49	0	0	0	0	0	0	46	26	14	6	4	168	1600	0.52	14.5	9.52	.00000930
97	7047904	1987	6	18	1000	1180	77.0	414.18	67	130	0	0	0	0	0	0	0	0	100	99	99	98	0	0	0	0	0	0	0	0	0	0	0	100	98	69	27	5	176	1890	0.62	15.1	10.70	.00000968
98	7047904	1987	11	20	1000	2990	53.6	2107.05	67	261	0	0	0	0	0	0	0	0	100	99	97	95	0	0	0	0	0	0	0	0	0	0	0	100	89	12	3	2	183	2020	1.48	16.0	11.00	.00001333
99	7047904	1987	12	10	845	2410	40.2	624.67	67	96	0	0	0	0	0	0	0	100	97	95	95	94	0	0	0	0	0	0	0	0	0	0	0	100	90	25	3	2	180	1810	1.35	15.1	10.10	.00001461
100	7047904	1988	1	23	1100	15300	39.2	9707.85	67	235	0	0	0	0	0	0	0	0	100	95	71	65	0	0	0	0	0	0	0	0	0	0	0	0	100	98	25	4	272	5050	3.03	32.7	17.30	.00001697
101	7047904	1988	2	19	900	10100	42.8	3299.67	67	121	0	0	0	0	0	0	0	0	100	98	83	73	0	0	0	0	0	0	0	0	0	0	0	100	96	95	55	23	213	3650	2.77	24.5	17.10	.00001508
102	7047904	1988	3	17	810	7900	47.3	1237.14	67	58	0	0	0	0	0	0	0	0	100	96	64	46	0	0	0	0	0	0	0	0	0	0	0	0	100	99	73	29	200	3150	2.51	25.2	15.70	.00001486
103	7047904	1988	4	14	800	6840	64.8	1865.27	67	101	0	0	0	0	0	0	0	0	100	98	91	85	0	0	0	0	0	0	0	0	0	0	0	100	68	12	4	4	200	2900	2.36	21.5	14.50	.00001201
104	7047904	1988	5	27	800	2660	69.8	746.93	67	104	0	0	0	0	0	0	0	0	100	98	96	91	0	0	0	0	0	0	0	0	0	0	0	100	80	37	8	4	183	2090	1.08	16.7	11.40	.00001058
105	7047904	1988	6	22	1230	397	82.4	70.75	67	66	0	0	0	0	0	0	0	0	0	100	98	89	0	0	0	0	0	0	0	0	0	0	0	100	86	29	9	5	149	1340	0.34	19.8	9.00	.00000909

OBS	STATION	YEAR	MONTH	DAY	TIME	FLOW	TEMP	SEDFLOW	CHANNEL	CONC	SSSA	SSSB	SSSC	SSSD	SSSE	SSSF	SSFA	SSFB	SSFC	SSFD	SSFE	SSFF
1	7040070	1977	11	15	930	1470	51.8	428.65	0	108	0	0	100	99	91.00	79.29	0	0	0	0	0	0
2	7040070	1977	12	13	1400	4070	37.4	8428.56	0	767	0	0	0	0	0.00	0.00	0	0	100	99	75	67
3	7040070	1978	2	28	1300	1220	37.4	770.80	0	234	0	100	95	73	56.00	52.00	0	0	0	0	0	0
4	7040070	1978	4	18	1015	2040	63.5	10244.88	0	1660	0	0	0	0	0.00	0.00	0	0	100	98	59	34
5	7040070	1978	5	17	1130	580	68.0	966.22	0	617	0	0	0	0	0.00	0.00	0	0	0	100	58	29
6	7040070	1978	6	21	1055	226	79.7	194.65	0	319	0	100	100	87	67.00	66.00	0	0	0	0	0	0
7	7040070	1978	7	26	1420	517	89.6	256.85	0	184	0	0	0	0	0.00	0.00	0	0	100	98	57	49
8	7040070	1978	8	29	1610	140	86.0	378.00	0	1000	0	0	0	0	0.00	0.00	0	100	100	96	61	49
9	7040070	1978	9	20	1630	245	86.9	66.81	0	101	0	0	100	86	45.00	34.00	0	0	0	0	0	0
10	7040070	1978	10	19	1050	290	59.9	1566.00	0	2000	0	0	0	0	0.00	0.00	0	0	100	94	34	30
11	7040070	1978	11	21	1445	591	50.0	722.85	0	453	0	0	0	0	0.00	0.00	0	0	100	97	80	75
12	7040070	1978	12	19	1230	2030	41.9	1907.39	0	348	0	0	0	0	0.00	0.00	0	0	100	92	78	65
13	7040070	1979	1	24	1100	5140	32.0	18901.84	0	1362	0	0	100	98	96.00	95.00	0	0	0	0	0	0
14	7040070	1979	2	21	1200	2720	39.2	5412.53	0	757	0	0	0	0	0.00	0.00	0	0	0	100	99	92
15	7040070	1979	3	21	1030	6290	50.0	3685.31	0	217	0	0	0	0	0.00	0.00	0	0	100	99	83	71
16	7040070	1979	4	19	1400	9110	59.9	12519.87	0	509	0	0	0	0	0.00	0.00	0	0	100	98	62	38
17	7040070	1979	5	23	1115	4600	66.2	2223.18	0	179	0	0	0	0	0.00	0.00	0	0	100	98	85	74
18	7040070	1979	6	20	1200	272	84.2	154.96	0	211	0	0	0	0	0.00	0.00	0	0	100	98	45	26
19	7040070	1979	7	25	1000	2820	78.8	56602.48	0	7434	0	0	0	0	0.00	0.00	0	0	0	100	94	93
20	7040070	1979	8	21	1100	220	85.1	39.80	0	67	0	0	0	0	0.00	0.00	0	0	100	94	86	80
21	7040070	1979	9	18	1100	169	70.7	19.62	0	43	0	0	0	0	0.00	0.00	0	0	100	97	65	60
22	7040070	1979	10	24	1345	110	62.6	71.87	0	242	0	0	0	0	0.00	0.00	0	0	100	98	19	14
23	7040070	1979	11	20	1300	478	55.4	392.34	0	304	0	0	0	0	0.00	0.00	0	0	100	99	34	19
24	7040070	1979	12	18	1430	1640	37.4	1757.92	0	397	0	0	0	0	0.00	0.00	0	0	100	96	41	31
25	7040070	1980	1	24	1200	672	41.0	344.74	0	190	0	0	0	0	0.00	0.00	0	0	100	99	34	26
26	7040070	1980	2	20	1015	3280	37.4	2789.64	0	315	0	0	0	0	0.00	0.00	0	0	100	99	80	70
27	7040070	1980	3	19	1620	1700	50.0	1386.18	0	302	0	0	0	0	0.00	0.00	0	0	100	99	78	65
28	7040070	1980	4	23	1030	2290	64.4	1267.52	0	205	0	0	0	0	0.00	0.00	0	0	100	99	39	33
29	7040070	1980	5	21	1000	1120	68.9	707.62	0	234	0	0	0	0	0.00	0.00	0	100	99	98	47	43
30	7040070	1980	6	18	930	170	71.6	30.75	0	67	0	0	0	0	0.00	0.00	0	0	100	96	73	70
31	7040070	1980	7	30	1000	222	84.2	26.37	0	44	0	0	0	0	0.00	0.00	0	0	0	100	98	95
32	7040070	1980	8	20	1230	135	89.6	25.51	0	70	0	0	0	0	0.00	0.00	0	0	100	98	95	88
33	7040070	1980	9	17	1130	127	69.8	31.20	0	91	0	0	0	0	0.00	0.00	0	0	100	97	89	86
34	7040070	1980	10	20	1430	109	65.3	30.31	0	103	0	0	0	0	0.00	0.00	0	0	100	99	98	96
35	7040070	1980	11	19	1215	267	48.2	35.32	0	49	0	0	0	0	0.00	0.00	0	0	100	98	80	74
36	7040070	1980	12	17	1215	571	43.7	1145.48	0	743	0	0	0	0	0.00	0.00	0	100	99	97	38	31
37	7040070	1981	1	21	1600	228	37.4	48.63	0	79	0	0	0	0	0.00	0.00	0	100	97	91	75	71
38	7040070	1981	2	18	1100	658	46.4	147.46	0	83	0	0	0	0	0.00	0.00	0	0	100	99	98	96
39	7040070	1981	3	24	1030	598	50.0	104.95	0	65	0	0	0	0	0.00	0.00	0	100	97	95	66	62
40	7040070	1981	4	21	1615	501	68.0	1286.42	0	951	0	0	0	0	0.00	0.00	0	0	100	99	99	99
41	7040070	1981	5	21	1230	2790	62.6	1875.72	0	249	0	0	0	0	0.00	0.00	0	0	100	99	86	79
42	7040070	1981	6	17	1215	3230	78.8	1369.20	0	157	0	0	0	0	0.00	0.00	0	0	100	98	83	75
43	7040070	1981	7	22	900	447	82.4	135.17	0	112	0	0	0	0	0.00	0.00	0	0	100	99	98	97
44	7040070	1981	8	18	1530	435	71.6	638.93	0	544	0	0	0	0	0.00	0.00	0	0	100	99	48	24
45	7040070	1981	9	23	1030	1490	68.0	2525.29	0	578	0	0	0	0	0.00	0.00	0	0	100	99	97	95
46	7040070	1981	10	21	1130	186	59.9	13.66	0	26	0	0	0	0	0.00	0.00	0	0	100	96	90	86
47	7040070	1981	11	16	1600	202	55.4	19.09	0	35	0	0	0	0	0.00	0.00	0	0	100	93	85	78
48	7040070	1981	12	16	830	379	41.0	19.44	0	19	0	0	0	0	0.00	0.00	0	0	100	97	95	82
49	7040070	1982	2	24	1300	6700	44.6	3762.72	0	208	0	0	0	0	0.00	0.00	0	0	100	99	77	60
50	7040070	1982	3	17	1230	4550	59.0	3058.97	0	249	0	0	0	0	0.00	0.00	0	0	100	98	86	78
51	7040070	1982	4	20	1200	1240	60.8	997.70	0	298	0	0	0	0	0.00	0.00	0	0	100	99	46	41
52	7040070	1982	5	19	1100	316	74.3	75.93	0	89	0	0	0	0	0.00	0.00	0	0	100	96	84	82
53	7040070	1982	6	23	815	1950	77.9	1074.06	0	204	0	0	0	0	0.00	0.00	0	0	100	99	70	62

OBS	BKSA	BKSB	BKSC	BKSD	BKSE	BKSF	BKSG	BKSH	BKSI	BKSJ	BKFA	BKFB	BKFC	BKFD	BKFE	BKFF	WIDTH	AREA	VEL	DEPMAX	DEPAVG	SLOPE	VISCOST
1	0	0	0	0	0	0	0	0	0	0	0	0	100	86.0	3.4	2	154	715.0	2.06	7.60	4.64	.0011057	.00001371
2	0	0	0	0	0	0	0	0	0	0	0	0	100	85.1	3.0	1	198	1500.0	2.71	12.70	7.58	.0017496	.00001731
3	0	0	0	0	0	0	0	0	0	0	0	100	99	75.0	2.0	1	168	691.0	1.77	9.70	4.11	.0011634	.00001764
4	0	0	0	0	0	0	0	0	0	0	0	100	98	88.0	11.0	1	166	1050.0	1.94	11.10	6.33	.0011057	.00001153
5	0	0	0	0	0	0	0	0	0	0	0	0	100	96.0	12.0	5	163	528.0	1.10	8.70	3.24	.0012843	.00001090
6	0	0	0	0	0	0	0	0	0	0	0	99	96	92.0	7.0	4	116	291.0	0.78	6.90	2.51	.0010823	.00000930
7	0	0	0	0	0	0	0	0	0	0	0	100	98	92.0	19.0	12	153	491.0	1.05	7.50	3.21	.0011346	.00000826
8	0	0	0	0	0	0	0	0	0	0	0	100	100	92.0	29.0	26	110	270.0	0.52	6.00	2.45	.0024639	.00000668
9	0	0	0	0	0	0	0	0	0	0	0	99	98	82.0	6.0	2	114	171.0	1.43	3.80	1.50	.0011400	.00000657
10	0	0	0	0	0	0	0	0	0	0	0	100	98	63.0	4.0	1	175	152.0	1.91	2.20	0.87	.0018903	.00001217
11	0	0	0	0	0	0	0	0	0	0	0	100	98	84.0	17.0	8	167	381.0	1.55	4.30	2.28	.0019030	.00001410
12	0	0	0	0	0	0	0	0	0	0	0	0	100	96.0	42.0	23	200	1580.0	1.28	10.80	7.90	.0012211	.00001639
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0	247	3080.0	1.67	17.40	12.47	.0001335	.00001931
14	0	0	0	0	0	0	0	0	0	0	0	100	98	70.0	41.0	12	201	1410.0	1.93	11.80	7.01	.0011995	.00001697
15	0	0	0	0	0	0	0	0	0	0	0	0	100	99.0	57.0	2	241	2610.0	2.41	18.80	10.83	.0006133	.00001410
16	0	0	0	0	0	0	0	0	0	0	0	100	99	93.0	36.0	4	262	3700.0	2.46	22.10	14.12	.0007377	.00001217
17	0	0	0	0	0	0	0	0	0	0	0	0	100	99.0	10.0	3	243	2360.0	1.95	18.20	9.71	.0006097	.00001122
18	0	0	0	0	0	0	0	0	0	0	0	0	100	95.0	1.0	1	95	200.0	1.36	4.30	2.11	.0010570	.00000888
19	0	0	0	0	0	0	0	0	0	0	0	0	100	97.0	2.0	1	163	874.0	3.23	8.30	5.36	.0007161	.00000923
20	0	0	0	0	0	0	0	0	0	0	0	100	98	91.0	5.0	4	92	315.0	0.70	6.10	3.40	.0010516	.00000878
21	0	0	0	0	0	0	0	0	0	0	0	0	100	93.0	1.0	1	120	115.8	1.44	2.40	0.97	.0010480	.00001045
22	0	0	0	0	0	0	0	0	0	0	100	99	98	90.0	2.0	1	111	86.8	1.27	1.72	0.78	.0010426	.00001169
23	0	0	0	0	0	0	0	0	0	0	0	0	100	91.0	0.0	0	195	292.0	1.64	2.60	1.50	.0010281	.00001314
24	0	0	0	0	0	0	0	0	0	0	0	0	100	97.0	2.0	1	210	735.0	2.23	9.50	3.50	.0013077	.00001764
25	0	0	0	0	0	0	0	0	0	0	0	0	100	96.0	4.0	1	130	420.0	1.60	6.90	3.23	.0011111	.00001639
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0	0.0	0	220	1600.0	2.05	13.80	7.27	.0009758	.00001764
27	0	0	0	0	0	0	0	0	0	0	0	0	100	96.0	6.0	3	210	914.0	1.86	6.90	4.35	.0012843	.00001410
28	0	0	0	0	0	0	0	0	0	0	0	0	100	94.0	1.0	0	202	847.0	2.70	9.40	4.19	.0010552	.00001153
29	0	0	0	0	0	0	0	0	0	0	0	100	98	91.0	6.0	5	112	483.0	2.32	7.70	4.31	.0011075	.00001073
30	0	0	0	0	0	0	0	0	0	0	0	100	98	90.0	2.0	2	98	273.0	0.62	5.90	2.79	.0009271	.00001032
31	0	0	0	0	0	0	0	0	0	0	0	100	99	92.0	3.0	2	103	163.0	1.36	2.08	1.58	.0011057	.00000888
32	0	0	0	0	0	0	0	0	0	0	0	100	97	71.0	13.0	12	107	224.0	0.60	3.30	2.09	.0011111	.00000826
33	0	0	0	0	0	0	0	0	0	0	0	100	99	89.0	1.0	1	120	127.0	1.00	1.90	1.06	.0010895	.00001058
34	0	0	0	0	0	0	0	0	0	0	0	100	97	74.0	14.0	11	104	222.0	0.49	5.00	2.13	.0010913	.00001138
35	0	0	0	0	0	0	0	0	0	0	0	100	99	85.0	1.0	1	144	210.0	1.27	2.15	1.46	.0011075	.00001461
36	0	0	0	0	0	0	0	0	0	0	0	100	98	91.0	0.0	0	86	234.0	2.44	5.60	2.72	.0016667	.00001562
37	0	0	0	0	0	0	0	0	0	0	0	100	99	77.0	1.0	1	103	194.0	1.18	5.30	1.88	.0011183	.00001764
38	0	0	0	0	0	0	0	0	0	0	0	100	99	86.0	2.0	2	119	348.0	1.09	5.20	2.92	.0011490	.00001511
39	0	0	0	0	0	0	0	0	0	0	0	100	99	79.0	1.0	1	117	323.0	1.85	5.40	2.76	.0011436	.00001410
40	0	0	0	0	0	0	0	0	0	0	0	100	99	77.0	2.0	2	120	282.0	1.78	4.70	2.35	.0011598	.00001090
41	0	0	0	0	0	0	0	0	0	0	0	100	99	95.0	1.0	1	220	1320.0	2.11	11.50	6.00	.0008838	.00001169
42	0	0	0	0	0	0	0	0	0	0	0	100	99	93.0	3.0	2	225	1600.0	2.02	12.40	7.11	.0009776	.00000943
43	0	0	0	0	0	0	0	0	0	0	0	100	99	82.0	1.0	1	157	312.0	1.43	2.75	1.99	.0011742	.00000909
44	0	0	0	0	0	0	0	0	0	0	0	100	99	98.0	14.0	2	154	269.0	1.62	3.30	1.75	.0010462	.00001032
45	0	0	0	0	0	0	0	0	0	0	0	100	99	92.0	2.0	1	206	648.0	2.30	5.30	3.15	.0011219	.00001090
46	0	0	0	0	0	0	0	0	0	0	0	100	99	87.0	1.0	1	95	140.0	1.33	2.74	1.47	.0010949	.00001217
47	0	0	0	0	0	0	0	0	0	0	0	100	99	79.0	1.0	1	125	152.0	1.33	3.10	1.22	.0010155	.00001314
48	0	0	0	0	0	0	0	0	0	0	0	100	99	85.0	3.0	3	205	417.0	0.91	4.50	2.03	.0010877	.00001639
49	0	0	0	0	0	0	0	0	0	0	0	100	99	89.0	1.0	0	248	2890.0	2.32	17.80	11.65	.0006800	.00001537
50	0	0	0	0	0	0	0	0	0	0	0	0	100	90.0	0.0	0	215	2050.0	2.22	13.80	9.53	.0008065	.00001236
51	0	0	0	0	0	0	0	0	0	0	0	0	100	97.0	1.0	1	158	527.0	2.35	7.50	3.34	.0010390	.00001201
52	0	0	0	0	0	0	0	0	0	0	0	0	100	88.0	0.0	0	126	282.0	1.12	2.92	2.24	.0010029	.00001007
53	0	0	0	0	0	0	0	0	0	0	0	100	99	92.0	1.0	1	212	812.0	2.40	6.00	3.83	.0010642	.00000956

ST. FRANCIS RIVER AT WILHELMINA, MO. 1978-1988

21:43 Thursday, December 30,

OBS	STATION	YEAR	MONTH	DAY	TIME	FLOW	TEMP	SEDFLOW	CHANNEL	CONC	SSSA	SSSB	SSSC	SSSD	SSSE	SSSF	SSFA	SSFB	SSFC	SSFD	SSFE	SSFF	BMSA	BMSB	BMSC	BMSD	BMSE	BMSF	BMSG	BMSH	BMSI	BMSJ	BMFA	BMFB	BMFC	BMFD	BMFE	BMFF	WIDTH	AREA	VEL	DEPMAX	DEPAVG	SLOPE	VISCOSITY
54	7040070	1982	8	26	1250	1140	76.1	1274.29	0	414	0	0	0	0	0	0	0	0	100	99	96	94	0	0	0	0	0	0	0	0	0	0	0	100	99	89	1	1	211	665	1.71	4.9	3.15	.0012907	.00000981
55	7040070	1982	9	21	1430	2370	71.6	799.87	0	125	0	0	0	0	0	0	0	0	100	99	85	76	0	0	0	0	0	0	0	0	0	0	0	0	100	99	20	1	221	1270	1.87	10.6	5.75	.0010426	.00001032
56	7040070	1982	11	16	1115	338	47.0	19.16	0	21	0	0	0	0	0	0	0	0	0	100	88	62	0	0	0	0	0	0	0	0	0	0	0	100	99	95	10	2	107	296	1.14	6.2	2.77	.0009632	.00001568
57	7040070	1982	11	29	1400	1760	46.4	1160.99	0	246	0	0	0	0	0	0	0	0	100	99	94	91	0	0	0	0	0	0	0	0	0	0	0	100	99	91	1	1	211	926	1.90	9.7	4.39	.0009181	.00001512
58	7040070	1983	1	11	830	9820	44.6	9571.55	0	361	0	0	0	0	0	0	0	0	100	99	43	32	0	0	0	0	0	0	0	0	0	0	0	100	96	84	4	3	262	3330	2.95	19.9	12.71	.0007035	.00001562
59	7040070	1983	2	14	1400	3460	42.8	1279.85	0	137	0	0	0	0	0	0	0	0	100	98	67	57	0	0	0	0	0	0	0	0	0	0	0	0	100	95	0	0	211	1720	2.01	13.7	8.15	.0007287	.00001568
60	7040070	1983	3	14	1330	1550	51.8	652.86	0	156	0	0	0	0	0	0	0	0	100	97	30	27	0	0	0	0	0	0	0	0	0	0	0	100	99	80	0	0	166	790	1.96	8.9	4.76	.0010227	.00001371
61	7040070	1983	4	11	1140	1910	53.6	691.04	0	134	0	0	0	0	0	0	0	0	100	99	92	78	0	0	0	0	0	0	0	0	0	0	0	100	99	66	5	5	182	1080	1.77	9.9	5.93	.0010137	.00001333
62	7040070	1983	5	9	1130	10200	62.6	5831.48	0	212	0	0	0	0	0	0	0	0	100	99	80	65	0	0	0	0	0	0	0	0	0	0	0	100	99	93	2	1	257	3690	2.76	22.2	14.36	.0006944	.00001169
63	7040070	1983	6	14	1200	1320	73.4	449.06	0	126	0	0	0	0	0	0	0	0	100	99	84	70	0	0	0	0	0	0	0	0	0	0	100	99	56	47	6	5	100	825	1.61	9.9	4.58	.0009542	.00001020
64	7040070	1983	11	9	1230	1250	59.0	850.25	0	252	0	0	0	0	0	0	0	0	100	99	83	76	0	0	0	0	0	0	0	0	0	0	0	0	100	89	0	0	176	660	1.89	6.5	3.75	.0009255	.00001236
65	7040070	1984	1	16	1200	5020	35.6	1003.00	0	74	0	0	0	0	0	0	0	0	100	99	90	76	0	0	0	0	0	0	0	0	0	0	0	0	100	90	4	1	241	2300	2.18	17.5	9.54	.0006606	.00001798
66	7040070	1984	2	13	1300	6340	50.0	15115.19	0	883	0	0	0	0	0	0	0	0	100	99	96	94	0	0	0	0	0	0	0	0	0	0	0	100	98	74	3	3	254	2920	2.17	18.7	11.64	.0005375	.00001410
67	7040070	1984	3	12	1235	2870	45.5	1255.34	0	162	0	0	0	0	0	0	0	0	100	96	65	34	0	0	0	0	0	0	0	0	0	0	0	100	99	85	2	1	220	1200	2.39	10.2	5.45	.0007594	.00001512
68	7040070	1984	4	16	1130	3700	59.0	1061.84	0	106	0	0	0	0	0	0	0	0	100	98	79	64	0	0	0	0	0	0	0	0	0	0	0	100	99	84	1	1	232	1800	2.05	12.0	8.02	.0007341	.00001236
69	7040070	1984	5	14	1230	3570	68.0	1426.57	0	148	0	0	0	0	0	0	0	0	100	97	82	66	0	0	0	0	0	0	0	0	0	0	0	100	99	93	5	2	232	1810	1.97	13.7	7.80	.0007973	.00001090
70	7040070	1984	6	4	1200	1120	77.0	359.86	0	119	0	0	0	0	0	0	0	0	100	97	54	51	0	0	0	0	0	0	0	0	0	0	0	100	99	85	1	1	198	562	1.97	6.7	2.84	.0007486	.00000968
71	7040070	1984	6	18	1150	331	86.0	51.84	0	58	0	0	0	0	0	0	0	0	100	97	82	79	0	0	0	0	0	0	0	0	0	0	0	100	99	85	2	2	111	228	1.45	6.2	2.05	.0008568	.00000664
72	7040070	1984	11	27	1300	11900	46.4	39641.20	67	1240	0	0	0	0	0	0	0	0	100	99	69	64	0	0	0	0	0	0	0	0	0	0	0	100	99	94	1	0	261	3390	3.51	19.9	12.99	.0008261	.00001512
73	7040070	1984	12	17	1430	4420	48.2	966.65	67	81	0	0	0	0	0	0	0	0	100	98	90	78	0	0	0	0	0	0	0	0	0	0	0	0	100	92	3	1	244	2140	2.07	16.5	8.92	.0004455	.00001461
74	7040070	1985	1	14	1430	10200	35.6	6168.96	67	224	0	0	0	0	0	0	0	0	100	99	52	38	0	0	0	0	0	0	0	0	0	0	0	100	99	86	5	4	260	3800	2.68	22.0	14.62	.0006512	.00001790
75	7040070	1985	2	11	1315	3210	33.8	3492.80	67	445	0	0	0	0	0	0	0	0	100	99	92	90	0	0	0	0	0	0	0	0	0	0	0	0	100	88	1	1	182	1380	2.33	15.3	7.58	.0007287	.00001864
76	7040070	1985	3	11	1430	5930	50.0	2385.64	67	149	0	0	0	0	0	0	0	0	100	99	95	85	0	0	0	0	0	0	0	0	0	0	0	100	99	82	1	1	240	2740	2.16	19.3	11.42	.0004924	.00001410
77	7040070	1985	4	8	1300	8580	53.6	3938.22	67	170	0	0	0	0	0	0	0	0	100	99	84	73	0	0	0	0	0	0	0	0	0	0	0	100	99	85	2	2	259	3160	2.72	19.8	12.20	.0005141	.00001333
78	7040070	1985	5	13	1330	3370	68.0	919.00	67	101	0	0	0	0	0	0	0	0	100	97	72	67	0	0	0	0	0	0	0	0	0	0	0	100	99	83	1	1	230	1570	2.15	13.5	6.83	.0006133	.00001090
79	7040070	1985	6	11	1300	3620	75.2	1407.46	67	144	0	0	0	0	0	0	0	0	100	98	88	81	0	0	0	0	0	0	0	0	0	0	0	100	99	87	1	1	230	1450	2.50	11.8	6.30	.0008063	.00000994
80	7040070	1985	11	18	1300	3530	55.4	2439.94	67	256	0	0	0	0	0	0	0	0	100	98	89	78	0	0	0	0	0	0	0	0	0	0	0	100	99	80	1	1	233	1570	2.25	11.3	6.74	.0007684	.00001314
81	7040070	1985	12	16	1400	4740	37.4	2802.76	67	219	0	0	0	0	0	0	0	0	100	88	72	54	0	0	0	0	0	0	0	0	0	0	0	100	99	66	1	1	235	2260	2.10	14.6	9.62	.0004960	.00001764
82	7040070	1986	1	21	1330	2540	39.2	932.69	67	136	0	0	0	0	0	0	0	0	100	97	64	56	0	0	0	0	0	0	0	0	0	0	0	100	99	77	1	1	223	1220	2.08	9.5	5.47	.0008550	.00001697
83	7040070	1986	2	18	1300	2210	40.1	1300.81	67	218	0	0	0	0	0	0	0	0	100	94	59	54	0	0	0	0	0	0	0	0	0	0	0	100	98	59	1	1	222	972	2.27	9.5	4.38	.0004600	.00001664
84	7040070	1986	3	17	1330	3210	50.0	1880.74	67	217	0	0	0	0	0	0	0	0	100	97	80	68	0	0	0	0	0	0	0	0	0	0	0	100	99	84	3	2	227	1580	2.03	12.5	6.96	.0007143	.00001410
85	7040070	1986	4	21	1330	4080	54.5	4208.11	67	382	0	0	0	0	0	0	0	0	0	0	100	95	0	0	0	0	0	0	0	0	0	0	0	100	99	75	5	4	240	2040	2.00	11.4	8.50	.0005682	.00001314
86	7040070	1986	5	19	1230	855	64.4	521.72	67	226	0	0	0	0	0	0	0	0	0	100	98	97	0	0	0	0	0	0	0	0	0	0	0	100	99	82	1	1	210	1110	0.77	10.1	5.29	.0020707	.00001153
87	7040070	1986	6	16	1415	2880	81.5	1609.63	67	207	0	0	0	0	0	0	0	0	100	98	83	78	0	0	0	0	0	0	0	0	0	0	0	100	98	47	1	0	230	1400	2.06	9.5	6.09	.0008424	.00000909
88	7040070	1986	11	17	1330	165	50.0	3.56	67	8	0	0	0	0	0	0	0	0	0	100	96	88	0	0	0	0	0	0	0	0	0	0	0	100	98	54	4	4	170	231	0.71	4.3	1.36	.0005736	.00001410
89	7040070	1986	12	15	1315	1570	41.9	534.11	67	126	0	0	0	0	0	0	0	0	100	91	59	54	0	0	0	0	0	0	0	0	0	0	0	100	97	65	19	16	218	828	1.90	7.0	3.80	.0006676	.00001613
90	7040070	1987	1	20	1415	674	39.2	98.27	67	54	0	0	0	0	0	0	0	0	0	100	99	99	0	0	0	0	0	0	0	0	0	0	0	100	99	68	0	0	118	441	1.53	5.4	3.74	.0006890	.00001698
91	7040070	1987	2	23	1315	1270	38.3	504.06	67	147	0	0	0	0	0	0	0	0	100	94	48	42	0	0	0	0	0	0	0	0	0	0	0	100	99	77	1	1	220	660	1.92	6.3	3.00	.0009325	.00001731
92	7040070	1987	3	16	1230	1680	51.8	612.36	67	135	0	0	0	0	0	0	0	0	100	97	76	67	0	0	0	0	0	0	0	0	0	0	0	100	99	81	1	1	220	848	1.98	7.9	3.85	.0007359	.00001371
93	7040070	1987	4	13	1300	668	62.6	128.06	67	71	0	0	0	0	0	0	0	0	100	96	81	74	0	0	0	0	0	0	0	0	0	0	0	100	99	82	2	1	114	395	1.69	6.3	3.46	.0009091	.00001169
94	7040070	1987	5	18	1350	228	81.5	31.40	67	51	0	0	0	0	0	0	0	0	0	100	99	98	0	0	0	0	0	0	0	0	0	0	0	100	99	86	10	2	71	185	1.23	4.5	2.61	.0009019	.00000909
95	7040070	1987	6	15	1300	213	75.2	40.26	67	70	0	0	0	0	0	0	0	0	0	100	97	97	0	0	0	0	0	0	0	0	0	0	0	100	98	72	2	2	125	183	1.16	4.8	1.22	.0006890	.00000994
96	7040070	1987	11	17	1345	800	55.4	3002.40	67	1390	0	0	0	0	0	0	0	0	0	100	99	98	0	0	0	0	0	0	0	0	0	0	0	0	100	98	75	39	217	625	1.28	4.5	2.87	.0009848	.00001314
97	7040070	1987	12	7	1300	1560	44.6	1469.99	67	349	0	0	0	0	0	0	0	0	100	99	92	90	0	0	0	0	0	0	0	0	0	0	0	100	99	92	15	5	220	836	1.87	8.0	3.80	.0004730	.00001537
98	7040070	1988	1	20	1400	7530	40.1	5245.44	67	258	0	0	0	0	0	0	0	0	100	99	96	93	0	0	0	0	0	0	0	0	0	0	0	100	99	80	18	3	260	3600	2.08	20.2	13.85	.0005087	.00001664
99	7040070	1988	2	16	1245	2250	37.4	1075.28	67	177	0	0	0	0	0	0	0	0	100	96	32	25	0	0	0	0	0	0	0	0	0	0	0	100	97	74	5	4	222	1130	1.99	8.0	5.09	.0009181	.00001764
100	7040070	1988	3	14	1300	2190	49.1	1046.60	67	177	0	0	0	0	0	0	0	0	100	96	65	59	0	0	0	0	0	0	0	0	0	0	0	100	97	71	5	4	220	1180	1.86	10.0	5.36	.0008820	.00001435
101	7040070	1988	4	11	1400	3000	59.0	1117.00	67	138	0	0	0	0	0	0	0	0	100	96	82	75	0	0	0	0	0	0	0	0	0	0	0	100	99	83	2	1	228	1290	2.33	12.9	5.66	.0008369	.00001236
102	7040070	1988	5	24	1245	603	69.8	177.44	67	109	0	0	0	0	0	0	0	0	100	97	86	85	0	0	0	0	0	0	0	0	0	0	0	100	98	69	1	1	128	395	1.53	6.6	3.09	.0004942	.00001058
103	7040070	1988	6	20	1315	289	86.0	44.48	67	57	0	0	0	0	0	0	0	0	100	99	98	96	0	0	0	0	0	0	0	0	0	0	0	100	99	81	2	1	146	274	1.05	2.1	1.47	.0011742	.00000868

SAMPLE SUPERCALC OUTPUT

Slope computations for Fisk

	A	B	C	D	E	F	G
1		FISK, MO ZERO=			GLENNONVILLE, MO		
2	DATE	GAGE HT	307.46	DATE	GAGE HT	287.74	SLOPE
3	10/19/77	3.17		10/20/77	2.35		.0001706
4	11/15	7.72			4.42		.0001912
5	12/14	14.62			11.37		.0001908
6	2/27/78	5.55		2/28/78	4.13		.0001756
7	3/22	20.48		NOT MADE			.0003339
8	4/18	8.57			5.34		.0001906
9	5/17	3.84		5/18	2.78		.0001726
10	6/22	.59		6/21	1.95		.0001525
11	7/26	4.31			2.8		.0001764
12	8/31	4.61		8/30	9.93		.0001196
13	9/20	1.98		9/21	2.04		.0001633
14	10/19	1.3		10/20	1.77		.0001599
15	11/21	4.54		11/22	2.91		.0001773
16	12/19	10.72		12/20	5.1		.0002105
17	1/25/79	11.58			6.4		.0002068
18	2/22	NOTMADE		2/21	6.12		.0001130
19	3/22	19.78		3/21	10.52		.0002407
20	4/20	22.36		4/19	12.94		.0002421
21	5/24	16.46		5/23	8.92		.0002264
22	6/21	2.05		6/20	1.78		.0001661
23	7/25	.7		7/26	2.13		.0001519
24	8/22	.86		8/21	1.57		.0001579
25	9/19	.39		9/18	1.22		.0001569
26	10/25	NOTMADE		10/24	.95		.0001559
27	11/20	3.08			2.07		.0001722
28	12/19	10.76			4.72		.0002140
29	1/25/80	4.36		1/24/80	2.46		.0001796
30	2/19	12.48		2/20	6.69		.0002119
31	3/20	8.36			4.44		.0001964
32	4/23	11.02			5.32		.0002112
33	5/21	7.59			3.59		.0001970
34	6/18	1.1			1.29		.0001622
35	7/30	.94			1.37		.0001602
36	8/21	.16		8/20	1.02		.0001567
37	9/17	.26			1.01		.0001576
38	10/21	.28		10/20	.92		.0001585
39	11/19	2.07			1.55		.0001681
40	12/17	10.07			4.22		.0002124
41	1/22/81	.6			1.4		.0001572
42	2/18	4.4			2.7		.0001779
43	3/25	3.92		3/24	2.37		.0001767
44	4/22	1		4/21	2.1		.0001547
45	5/21	13.56			6.42		.0002231
46	6/17	13.07			6.4		.0002192
47	7/23	11.96		7/22	2.63		.0002413
48	8/19	1.84		8/18	2.06		.0001620
49	9/24	9.82		9/23	4.14		.0002110
50	10/21	.59			1.28		.0001581
51	11/17	1.57			1.11		.0001676
52	12/16	3.22			1.86		.0001751
53	1/20/82	2.44			2.74		.0001613
54	2/24	20.24			11.06		.0002401
55	3/17	12.91			6.93		.0002135
56	4/20	7.02			3.82		.0001904
57	5/19	.95			1.88		.0001561
58	6/22	10.12			4.89		.0002073
59	7/21	.92			1.49		.0001591
60	8/25	.13			4.88		.0001244
61	9/22	12.05			5.73		.0002163

	A	B	C	D	E	F	G
62	10/19	2.44		NOT MADE			
63	11/15	2.33		11/16	1.76		.0001685
64	11/29	6.22		11/30	4.1		.0001814
65	1/10/83	22.07		1/11/83	13.72		.0002332
66	2/14	15.24		2/15	7		.0002323
67	3/15	7.78			4.09		.0001945
68	4/13	11.06			5.41		.0002107
69	5/9	22.21		5/10	13.78		.0002338
70	6/14	6.64		6/13	4.34		.0001829
71	7/12	1.19		NOT MADE			
72	8/8	.35		NOT MADE			
73	9/13	-.63		NOT MADE			
74	10/20	1.96		NOT MADE			
75	11/9	9.71			3.65		.0002141
76	1/16/84	16.84			8.68		.0002316
77	2/13	5.32			9.78		.0001268
78	3/12	11.52			5.64		.0002127
79	4/16	14.22			7.55		.0002192
80	5/14	13.52			7.12		.0002170
81	6/4	5.76			3.61		.0001817
82	6/18	1.11			1.82		.0001579
83	7/16	1.45		NOT MADE			.0001759
84	8/13	-.5		NOT MADE			.0001597
85	9/11	-.86		NOT MADE			.0001567
86	10/22	12.82		NOT MADE			.0002703
87	11/27	15.98			13.88		.0001813
88	12/18	15.09		12/17	8		.0002227
89	1/14/85	22.73			14.22		.0002345
90	2/11.	6.7			6.56		.0001650
91	3/11	16.73			10.24		.0002177
92	4/8	21.66			13		.0002357
93	5/13	12.76			7.09		.0002109
94	6/11	13.7			6.92		.0002201
95	7/15	13.75		NOT MADE			
96	8/12	6.65		NOT MADE			
97	9/16	3.21		NOT MADE			
98	10/15	.77		NOT MADE			
99	11/18	14.56			6.92		.0002273
100	12/16	15.94			8.05		.0002293
101	1/21/86	10.7			5.77		.0002048
102	2/18	8.32			5.36		.0001884
103	3/17	11.31			6.27		.0002057
104	4/21	8.73			7.63		.0001729
105	5/19	2.09			2.91		.0001570
106	6/16	12.22			6.4		.0002122
107	7/21	1.13		NOT MADE			
108	8/26	-.49		NOT MADE			
109	9/16	-.17		NOT MADE			
110	10/21	.63		NOT MADE			
111	11/17	-.93			1.12		.0001468
112	12/15	6.47			3.68		.0001870
113	1/20/87	3.17			2.48		.0001695
114	2/23	6.8			3.91		.0001878
115	3/16	8.05			4.5		.0001933
116	4/13	3.21			2.62		.0001687
117	5/18	-.54			1.83		.0001441
118	6/15	-.8			1.28		.0001465
119	7/13	4.28		NOT MADE			
120	8/18	1.33		NOT MADE			
121	9/15	.66		NOT MADE			
122	10/13	-1.01		NOT MADE			

	A	B	C	D	E	F	G
123	11/17	-.8			2.65		.0001352
124	12/7	5.12			4.1		.0001723
125	1/20/88	14.47			11.47		.0001887
126	2/16	8.72			5.52		.0001904
127	3/14	9.21			5.52		.0001945
128	4/11	11.11			6.42		.0002028
129	5/24	1.01			2.3		.0001531
130	6/20	.15			1.54		.0001523
131	7/19	-.32		NOT MADE			
132	8/15	-1.18		NOT MADE			
133	9/12	-.28		NOT MADE			

SAMPLE SAM INPUT AND OUTPUT

Wilhelmina, November 15, 1977

```
**************************************************
*                        *
*  HYDRAULIC DESIGN PACKAGE FOR FLOOD CONTROL  *
*          CHANNELS (SAM)          *
*                        *
*    SEDIMENT TRANSPORT CALCULATIONS        *
*                        *
* VERSION 3.05              31 March 1993 *
*                        *
*          A Product of the          *
*  Flood Control Channels Research Program    *
*Hydraulics Laboratory, Waterways Experiment Station*
**************************************************
```

Msg 1: SED. READING INPUT DATA FROM FILE [sed.in] THIS DIRECTORY.

TABLE 1. LIST INPUT DATA.

```
TI WILCO 77/11/15
TF TOFFALETI.        YES
TF YANG.        YES
TF ACKER-WHITE.        YES
TF COLBY        YES
TF TOFFALETI-SCHOKLITSC YES
TF MPM(1948).        YES
TF BROWNLIE,D50        YES
TF TOFFALETI-MPM        YES
TF LAURSEN(MADDEN),1985 YES
TF LAURSEN(COPELAND)    YES
TF YANG,D50        YES
TF ACKER-WHITE,D50    YES
TF MPM(1948),D50        YES
F# 45678 2345678 2345678 2345678 2345678 2345678 2345678 2345678 2345678
2345678
TR   -1
VE 2.06
DE  4.64
WI 154.
QW 1470.
ES111E-5
WT 51.8
PF            0.5   0.5   100.   .25   86.0   .125   3.4
PFC.0625   2.0
$JOB
```

1

TABLE 5.0 SUMMARY TABLE: TOTAL BED-MATERIAL SEDIMENT DISCHARGE, TONS/DAY

Q NO	WATER DISCHARGE	TRANSPORT FUNCTIONS TOFFALETI.	YANG. (HEC-6)	ACKER-WHITE (HEC-6)	COLBY (HEC-6)
1	1470.	1455.	3861.	22002.	858.

Q NO	WATER DISCHARGE	TRANSPORT FUNCTIONS TOFFALITI-SCHOKLITSCH	MPM(1948) (HEC-6)	BROWNLIE, D50	TOFFALETI-MPM
1	1470.	2968.	187.	1474.	1642.

Q NO	WATER DISCHARGE	TRANSPORT FUNCTIONS LAURSEN (MADDEN), 85	LAURSEN (COPELAND)	YANG,D50	ACKER-WHITE, D50
1	1470.	6326.	1629.	3819.	5153.

Q NO	WATER DISCHARGE	TRANSPORT FUNCTIONS MPM(1948), D50
1	1470.	194.

End of Job PRINTOUT SAVED IN FILE sed.out
1

SAMPLE STATGRAPHICS INPUT

Observed water and sediment discharge, computed bed material transport, water year 1978, Fisk

FILE: FISK1 05/30/96 09:58:05 AM Page 1

Row	FLOW	OBSQS	SANDQS	TOFF
1	303.	33.54	7.38	1.
2	925.	177.32	77.12	8.
3	2860.	1436.29	1133.23	79.
4	654.	63.57	27.34	2.
5	5600.	1723.68	1172.10	1286.
6	1250.	600.75	474.59	14.
7	352.	233.80	147.29	1.
8	38.	7.82	3.44	1.
9	433.	122.76	45.42	1.
10	475.	374.49	112.35	1.
11	195.	70.03	30.11	1.

FILE: FISK1 05/30/96 09:58:05 AM Page 2

Row	YANGH6	AWH6	COLBY6	TFSCH
1	7.	1.10000000E1	1.	1.
2	92.	1.16900000E3	1.	39.
3	350.	1.12280000E4	130.	190.
4	24.	4.10000000E1	96.	3.
5	3853.	3.60742000E5	391.	2304.
6	83.	1.65000000E2	1.	31.
7	10.	1.40000000E1	1.	1.
8	1.	1.00000000E0	1.	1.
9	13.	9.00000000E0	1.	2.
10	4.	9.00000000E0	1.	1.
11	2.	1.00000000E0	1.	1.

FILE: FISK1 05/30/96 09:58:05 AM Page 3

Row	MPMH6	BROWN	TOFMPM	LRSMAD
1	1.	2.	1.	1.
2	7.	18.	15.	1.
3	34.	186.	113.	1057.
4	3.	8.	5.	17.
5	133.	1350.	1419.	15170.
6	9.	37.	24.	82.
7	1.	2.	1.	1.
8	1.	1.	1.	1.
9	1.	5.	3.	1.
10	1.	2.	1.	1.
11	1.	1.	1.	1.

FILE: FISK1 05/30/96 09:58:05 AM Page 4

Row	LRSCOP	YANG50	AW50	MPM
1	4.	7.	4.	0.
2	82.	69.	123.	8.
3	245.	318.	393.	41.
4	18.	22.	12.	2.
5	2246.	3116.	13580.	145.
6	38.	78.	46.	11.
7	5.	10.	5.	1.
8	1.	1.	1.	0.
9	5.	15.	7.	1.
10	3.	18.	78.	2.
11	3.	2.	1.	0.

SAMPLE QUATTRO-PRO INPUT

Partial entropy calculation file, Fisk, MO

INTERVAL 100	YANG HEC6 FISKARTH FREQUENCY	101 PROBABILITY	OBSV ENTROPY
1	54	0.53465346535	0.33476603361
2	7	0.06930693069	0.18499477797
3	5	0.0495049505	0.14879616854
4	6	0.05940594059	0.16772441867
5	7	0.06930693069	0.18499477797
6	4	0.0396039604	0.1278743032
7	3	0.0297029703	0.10445073945
8	6	0.05940594059	0.16772441867
9	1	0.0099009901	0.04569426254
10	1	0.0099009901	0.04569426254
11	1	0.0099009901	0.04569426254
12	0	0	0
13	0	0	0
14	1	0.0099009901	0.04569426254
15	0	0	0
16	0	0	0
17	0	0	0
18	1	0.0099009901	0.04569426254
19	0	0	0
20	0	0	0
21	1	0.0099009901	0.04569426254
22	0	0	0
23	0	0	0
24	0	0	0
25	1	0.0099009901	0.04569426254
26	0	0	0
27	1	0.0099009901	0.04569426254
28	0	0	0
29	0	0	0
30	0	0	0
31	0	0	0
32	0	0	0
33	0	0	0
34	0	0	0
35	0	0	0
36	0	0	0
37	0	0	0
38	0	0	0
39	1	0.0099009901	0.04569426254
40	0	0	0
	101	1	1.83257400095

	FISK10	93
FREQUENCY	PROBABILITY	ENTROPY
50	0.5376344086	0.33364327297
7	0.0752688172	0.19469704741
5	0.05376344086	0.15715922477
4	0.04301075269	0.13532495192
7	0.0752688172	0.19469704741
3	0.03225806452	0.11077378079
2	0.02150537634	0.08256886694
6	0.06451612903	0.17682838864
1	0.01075268817	0.04873762896
1	0.01075268817	0.04873762896
1	0.01075268817	0.04873762896
0	0	0
0	0	0
1	0.01075268817	0.04873762896
0	0	0
0	0	0
0	0	0
1	0.01075268817	0.04873762896
0	0	0
0	0	0
1	0.01075268817	0.04873762896
0	0	0
0	0	0
0	0	0
1	0.01075268817	0.04873762896
0	0	0
1	0.01075268817	0.04873762896
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
0	0	0
1	0.01075268817	0.04873762896
0	0	0
93	1	1.82433124146

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13. ABSTRACT ***(Maximum 200 words)***

Well over a century of research into the relationship between sediment and water and the amount of sediment transported under any given set of flow conditions has produced a prolific number of sediment transport relationships. These functions are based on measurable physical, sediment, and hydraulic parameters. By properly selecting one or more of these functions, sediment transport may be predicted for a variety of conditions.

Due to the nature of the sediment-water discharge relationship, which may vary over several log cycles for a given flow, a large amount of data are thought to be necessary to adequately define the sediment transport characteristics of a given stream or reach thereof. The collection of sediment data is expensive and time consuming. Little or not guidance has been developed to answer the question, "How much sediment data are necessary?"

A procedure to answer this question is developed in this dissertation. The procedure is tested at three different locations within the St. Francis river basin, which drains over 5,000 square miles in southeastern Missouri and Eastern Arkansas. A two-staged approach using the methods of regression analysis and the principle of maximum entropy is used to develop the procedure. In addition, a comprehensive data set is developed and is available for additional research. A by-product of the procedure is guidance on selecting the best sediment transport equation for a given reach of river. The procedure developed

(Continued)

14. SUBJECT TERMS

Data uncertainty	St. Francis River	Sediment transport
Entropy	Sediment data	
Regression analysis	Sediment sampling	

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herein will define the amount of an existing sediment data set that provides the most information and also evaluate the adequacy of the data set for describing sediment transport characteristics within a given basin.

The important results from this work are as follows:

a. A procedure has been developed to determine if a set of sediment samples is of sufficient length to provide the maximum amount of information for an alluvial system.

b. A procedure has been developed to verify the transport function that best predicts sediment transport for a steam or stream reach.

c. A procedure has been developed that will allow evaluation of the adequacy of existing data sets for selecting an appropriate sediment transport equation.

d. A set of sediment data samples has been assembled that is unprecedented in scope and completeness, and available in digital format.

e. In sight has been provided that will answer the question, "How much data are needed for a riverine sediment study?"